To Arch. C. Seton

With every good wish.

A. C.

Nov. 22/58

THE STORY OF A BOULDER.

THE STORY OF A BOULDER

OR

GLEANINGS FROM THE NOTE-BOOK OF A FIELD GEOLOGIST

BY

ARCHIBALD GEIKIE

OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN.

Illustrated with Woodcuts.

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TO

GEORGE WILSON, M.D., F.R.S.E.

REGIUS PROFESSOR OF TECHNOLOGY IN THE

UNIVERSITY OF EDINBURGH,

THESE PAGES

ARE

AFFECTIONATELY INSCRIBED.

PREFACE.

The present Volume has been written among the rocks which it seeks to describe, during the intervals of leisure of a field-geologist. Its composition has been carried on by snatches, often short and far apart, some of the descriptions having been jotted down on the spot by streamlet and hill-side, or in the quiet of old quarries ; others, again, in railway-carriage or stage-coach. By much the larger portion, however, has been written by the village fireside, after the field-work of the day was over—a season not the most favourable to any mental exercise, for weariness of body is apt to beget lassitude of mind. In short, were I to say that these Chapters have been as often thrown aside and resumed again as they contain paragraphs, the statement would probably not exceed the truth. But the erratic life of an itinerant student of science is attended with yet greater disadvantages. It entails an absence from all libraries, more especially scientific ones, and the number of works of reference admissible into his *parva supellex* must ever be few indeed. With these hindrances, can the writer venture to hope that what has thus been so disjointed and unconnected to him, will not seem equally so to his readers? Yet if his descriptions, written, as it were, face to face with Nature,

are found to have caught some tinge of Nature's freshness, and please the reader well enough to set him in the way of becoming a geologist, he shall have accomplished all his design.

It cannot be too widely known, or too often pressed on the attention, especially of the young, that a true acquaintance with science, so delightful to its possessors, is not to be acquired at second-hand. Text-books and manuals are valuable only so far as they supplement and direct our own observations. A man whose knowledge of Nature is derived solely from these sources, differs about as much from one who betakes himself to Nature herself, as a dusty, desiccated mummy does from a living man. You have the same bones and sinews in both ; but in the one they are hard and dry, wholly incapable of action ; in the other they are instinct with freshness and life. He who would know what physical science really is, must go out into the fields and learn it for himself ; and whatever branch he may choose, he will not be long in discovering that a forenoon intelligently spent there must be deemed of far more worth than days and weeks passed among books. He sees the objects of his study with his own eyes, and not through "the spectacles of books ;" facts come home to him with a vividness and reality they never can possess in the closet ; the free buoyant air brightens his spirits and invigorates his mind, and he returns again to his desk or his workshop with a store of new health and pleasure and knowledge. Geology is peculiarly rich in these advantages, and lies in a manner open to all. No matter what may be the season of the year, it offers always some material for observation. In the depth of winter we have the effects of ice and frost to fall back upon, though the country should lie buried in snow ; and then when the longer and

brighter days of spring and summer come round, how easily may the hammer be buckled round the waist, and the student emerge from the dust of town into the joyous air of the country, for a few delightful hours among the rocks; or when autumn returns with its long anticipated holidays, and preparations are made for a scamper in some distant locality, hammer and note-book will not occupy much room in the portmanteau, and will certainly be found most entertaining company. The following pages—forming a digest of the Carboniferous rocks—may, perhaps, in some measure, guide the explorations of the observer, by indicating to him the scope of geological research, the principles on which the science rests, and the mode in which it is pursued. But I repeat, no book, no lecture-room, no museum, will make a geologist of him. He must away to the fields and study for himself, and the more he can learn there he will become the better geologist.

He need not burden himself with accoutrements. A hammer, pretty stout in its dimensions, with a round blunt face and a flat sharp tail; a note-book and a good pocket-lens, are all he needs to begin with. Having these, let him seek to learn the general characters of the more common rocks, aiding himself, where he can, by a comparison with the specimens of a museum, or, failing that, with the descriptions of a text-book. Let him then endeavour to become acquainted with some of the more characteristic fossils of the district in which he resides, so as to be able to recognise them wherever they occur. Private collections and local museums are now becoming comparatively common, and these, where accessible, will aid him vastly in his studies. Having at length mastered the more abundant rocks and organic remains of his neighbourhood, let him try to trace out

the connexion of the different strata across the country, so as to understand its structure. For this purpose it will be necessary to examine every ravine and natural exposure of the rocks, along with quarries, ditches, railway-cuttings, and, in short, the whole surface of the district. A general notion of the geology of the place will not perhaps be of very difficult attainment; and this done, the observer should attempt to put down the connexion of the rocks on paper, for till this is accomplished he will have at the best but an imperfect, and perhaps incorrect notion of the subject. The best map of the district should be obtained, also a clinometer, or instrument for ascertaining the angle at which rocks *dip* with the horizon, and a pocket-compass with which to mark the direction of the *dip* and *strike* of strata, that is, the *outcrop*, or line which they form when they come to the surface. Thus armed, he may commence a geological survey of his neighbourhood. Wherever he sees a bed of rock exposed, it should be marked down on his map with an arrow pointing to the direction in which the stratum is dipping, the angle of dip, ascertained by the clinometer, being put alongside. The nature of the rock, whether sandstone, shale, limestone, or greenstone, must be set down at the same place, and, to save room, a system of marks for the different rocks may be conveniently used. When a sufficient area of ground has been thus traversed, the student may find, say a row of arrows on his map all pointing due west, and indicating a set of quarries about a quarter of a mile distant from one another, the rock in each of them dipping to the west. If there be at the one end a limestone containing certain fossils, and at the other end a stratum exactly similar, containing the same fossils, while the quarries between display the same rock, he will infer, of course,

that the whole is one limestone, and will accordingly draw a line from the last quarry on the north to the last on the south, connecting them all together. If the bed dips steeply down, the line will be narrower,—if but slightly inclined, it will be broader; the breadth of such a line (which may be coloured to taste) always varying with the thickness of the stratum and the angle which it makes with the horizon. In a district where faults and curvatures along with trap-rocks abound, the mapping becomes more complex, but the principle remains the same—a curved stratum on the ground making a similarly curved band on the map, and a fault or dislocation of a set of beds producing, in the same way, a corresponding break in the lines traced. In short, a geological map should be as far as possible a transcript of the surface rocks of a country. The beginner should avoid, however, attempting too much; it will be enough for him at first to have mastered the leading features of the geology of his district; the details cannot be shown save on a map of a large scale, and are better transferred to his note-book. The use of such mapping is to enable us to gain a correct knowledge of the geological structure of a country, and of the relation of rocks to each other as regards age, origin, &c. Bacon tells us that "writing makes an exact man;" we may say with equal truth that mapping makes an exact geologist. It is sometimes easy enough to obtain a notion of the general character of a district by taking a few rambles across it; but we can never know it thoroughly until we have mapped it. And this is done not as mere dry routine, or by a series of hard uninteresting rules. In reading off the geological structure of a country, we ascertain its history during many thousand ages long prior to that of man. We become, as it were,

interpreters of hieroglyphics, and historians of long-perished dynasties.

Those who have had experience of field-geology, know how vain it is to attempt to compress into a page or two the results of years, and that a few vague general directions are about the utmost that can be attempted. The practice of the science cannot be taught in books, far less in prefaces, neither can it be learned from them. And so I once more repeat the advice: Get away to the fields. Seek to decipher the geological records for yourself, and look with your own eyes into the long series of ages whose annals lie inscribed among the rocks. If you can secure the co-operation of a few companions, so much the better. Half-a-dozen hammers zealously at work in a richly fossiliferous stratum will soon pile up a tolerable collection of its treasures. But whether singly or in company, use your eyes and your hammer, and even though in the end you should never become a geologist, you will in the meantime gain health and vigour, and a clearness of observation, that will stand you in good stead through life.

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THE STORY OF A BOULDER.

CHAPTER I.

Scene near Colinton in midsummer—A grey travelled Boulder—Its aspect and contents—Its story of the past.

THREE miles to the south-west of Edinburgh, and not many hundred yards from the sequestered village of Colinton, there is a ravine, overshaded by a thick growth of beech and elm, and traversed beneath by a stream, which, rising far away among the southern hills, winds through the rich champaign country of Mid-Lothian. It is, at all seasons of the year, one of the most picturesque nooks in the county. I have seen it in the depth of winter—the leafless boughs doddered and dripping, the rocks dank and bare save where half-hidden by the rotting herbage, and the stream, red and swollen, roaring angrily down the glen, while the families, located along its banks, fleeing in terror to the higher grounds, had left their cottages to the mercy of the torrent. The last time I visited the place was in the heart of June, and surely never did woodland scene appear more exquisitely beautiful. The beech trees were in full leaf, and shot their silvery boughs in slender arches athwart the dell, intertwining with the broader foliage and deeper green of the elm, and the still darker spray of the stately fir. The rocks on either side were tapestried with

verdure; festoons of ivy, with here and there a thread of honeysuckle interwoven, hung gracefully from the cliffs overhead; each projecting ledge had its tuft of harebells, or speedwell, or dog-violets, with their blue flowers peeping out of the moss and lichens; the herb-robert trailed its red blossoms over crag and stone; the wood-sorrel nestled its bright leáves and pale flowerets among the gnarled roots of beech and elm; while high over all, alike on the rocks above and among the ferns below, towered the gently drooping stalks of the fox-glove. The stream, almost gone, scarcely broke the stillness with a low drowsy murmur, as it sauntered on among the *lapides adesos* of its pebbly channel. Horace's beautiful lines found again their realization:—

> "Qua pinus ingens, albaque populus
> Umbram hospitalem consociare amant
> Ramis, et obliquo laborat
> Lympha fugax trepidare rivo." [1]

It was noon, and the sun shone more brightly and with greater heat than had been felt for years. The air, heavy and warm, induced a feeling of listlessness and languor, and the day seemed one for which the only appropriate employment would have been to read once again the "Castle of Indolence." But failing that, I found it pleasant to watch the flickering light shot in fitful gleams through the thick canopy of leaves, and thus, in the coolness of the shade, to mark these rays—sole messengers from the sweltering world around—as they danced from rock to stream, now lighting up the ripples that curled dreamily on, now chequering some huge boulder that lay smooth and polished in mid-channel, anon glancing playfully among

[1] Where the tall pine and poplar pale
Delight to cast athwart the vale
A pleasing shade,
While the clear stream low murmuring boils,
And o'er its winding channel toils
Adown the glade.—A. G.

the thickets of briar or honeysuckle and vanishing in the shade. Sometimes a wagtail would alight at hand, or a bee drone lazily past, while even an occasional butterfly would venture down into this shady covert. But, with these exceptions, the animal creation seemed to have gone to sleep, an example which it was somewhat difficult to avoid following. While thus idly engaged, my eye rested on a large boulder on the opposite side. It lay partly imbedded in a stiff clay, and partly protruding from the surface of the bank some way above the stream. A thick arbour of leafage overhung it, through which not even the faintest ray of sunshine could force its way. The spot seemed cooler and more picturesque than that which I occupied, and so, crossing the well-nigh empty channel, I climbed the bank and was soon seated on the boulder. A stout hammer is a constant companion in my rambles, and was soon employed on this occasion in chipping almost unconsciously the newly-acquired seat. The action was, perhaps, deserving of the satire of Wordsworth's Solitary :—

> "You may trace him oft
> By scars, which his activity has left
> Beside our roads and pathways, though, thank Heaven!
> This covert nook reports not of his hand.
> He, who with pocket-hammer smites the edge
> Of luckless rock or prominent stone, disguised
> In weather-stains, or crusted o'er by Nature
> With her first growths, detaching by the stroke
> A chip or splinter—to resolve his doubts;
> And, with that ready answer satisfied,
> The substance classes by some barbarous name,
> And hurries on; or from the fragments picks
> His specimen; if but haply interveined
> With sparkling mineral, or should crystal cube
> Lurk in its cells—and thinks himself enriched,
> Wealthier, and doubtless wiser, than before!"

There was nothing in the distant aspect of the boulder to attract attention. It was just such a mass as dozens of others all round. Nor, on closer inspection, might anything peculiar

have been observed. It had an irregularly oblong form, about two or three feet long, and half as high. Ferns and herbage were grouped around it, the wood-sorrel clustered up its sides, and little patches of moss and lichen nestled in its crevices. And yet, withal, there was something about it that, ere long, riveted my attention. I examined it minutely from one end to the other, and from top to bottom. The more I looked the more did I see to interest me; and when, after a little labour, some portions of its upper surface were detached, my curiosity was abundantly gratified. That grey lichened stone, half hid among foliage, and unheeded by any human being, afforded me material for a pleasant forenoon's thought. Will my reader accept an expanded narrative of my reverie?

I can almost anticipate a smile. "What can there be remarkable in such a grey stone, hidden in a wood, and of which nobody knows anything? It never formed part of any ancient building; it marks the site of no event in the olden time; it is linked with nothing in the history of our country. What of interest, then, can it have for us?" Nay, I reply, you are therein mistaken. It is, assuredly, linked with the history of our country—it does mark the passing of many a historical event long ere human history began; and, though no tool ever came upon it, it did once form part of a building that rose under the finger of the Almighty during the long ages of a bygone eternity. To change the figure, this boulder seemed like a curious volume, regularly paged, with a few extracts from older works. Bacon tells us that "some books are to be tasted, others to be swallowed, and some few to be chewed and digested." Of the last honour I think the boulder fully worthy, and if the reader will accompany me, I shall endeavour to show him how the process was attempted by me.

The rock consisted of a hard grey sandstone finely laminated above, and getting pebbly and conglomeritic below. The included pebbles were well worn, and belonged to various

kinds of rock. The upper part of the block was all rounded, smoothed, and deeply grooved, and, when split open, displayed numerous stems and leaflets of plants converted into a black coaly substance. These plants were easily recognisable as well-known organisms of the carboniferous strata, and it became accordingly evident that the boulder was a block of carboniferous sandstone. The pebbles below, however, must have been derived from more ancient rocks, and they were thus seen to represent some older geological formation. In this grey rock, therefore, there could at once be detected well-marked traces of at least two widely-separated ages. The evidence for each was indubitable, and the chronology of the whole mass could not be mistaken. The surface striation bore undoubted evidence of the glacial period, the embedded plants as plainly indicated the far more ancient era of the coal-measures, while the pebbles of the base pointed, though dimly, to some still more primeval age. I had here, as it were, a quaint, old, black-letter volume of the middle ages, giving an account of events that were taking place at the time it was written, and containing on its earlier pages numerous quotations from authors of antiquity. The scratched surface, to complete the simile, may be compared to this old work done up in a modern binding. Let us, then, first of all, look for a little at the exterior of the volume, and inquire into the origin of that strangely-striated surface, and of the clay in which the boulder rested.

CHAPTER II.

Exterior of the boulder—Travelled stones a difficult problem—Once referred to the Deluge—Other theories—Novelty of the true solution—Icebergs formed in three ways—Progress and scenery of an iceberg—Its effects—Size of icebergs—Boulder-clay had a glacial origin—This explanation confirmed by fossil shells—Laws of the distribution of life—Deductions.

HAS the reader, when wandering up the course of a stream, rod in hand perhaps, ever paused at some huge rounded block of gneiss or granite damming up the channel, and puzzled himself for a moment to conjecture how it could get there ? Or when rolling along in a railway carriage, through some deep cutting of sand, clay, and gravel, did the question ever obtrude itself how such masses of water-worn material came into existence ? Did he ever wonder at the odd position of some huge grey boulder, far away among the hills, arrested as it were on the steep slope of a deep glen, or perched on the edge of a precipitous cliff, as though a push with the hand would hurl it down into the ravine below ? Or did he ever watch the operations of the quarryman, and mark, as each spadeful of soil was removed, how the surface of the rock below was all smoothed, and striated, and grooved ?

These questions, seemingly simple enough, involve what was wont to be one of the greatest problems of geology, and not many years have elapsed since it was solved. The whole surface of the country was observed to be thickly covered with a series of clays, gravels, and sands, often abounding in rounded masses of rock of all sizes up to several yards in diameter.

These deposits were seen to cover all the harder rocks, and to occur in a very irregular manner, sometimes heaped up into great mounds, and sometimes entirely wanting. They were evidently the results of no agency visible now, either on the land or around our coasts. They had an appearance rather of tumultuous and violent action, and so it was wisely concluded that they must be traces of the great deluge. The decision had at least this much in its favour, it was thoroughly orthodox, and accordingly received marked approbation, more especially from those who wished well to the young science of geology, but were not altogether sure of its tendencies. But, alas ! this promising symptom very soon vanished. As observers multiplied, and investigations were carried on in different countries, the truth came out that these clays and gravels were peculiarly a northern formation ; that they did not appear to exist in the south of France, Italy, Asia Minor, Syria, and the contiguous countries. If, then, they originated from the rushing of the diluvian waters, these southern lands must have escaped the catastrophe, and the site of the plains of Eden would have to be sought somewhere between the Alps and the North Pole. This, of course, shocked all previous ideas of topography ; it was accordingly agreed, at least among more thoughtful men, that with these clays and sands the deluge could have had nothing to do.

Other theories speedily sprang up, endeavouring to account for the phenomena by supposing great bodies of water rushing with terrific force across whole continents, sweeping away the tops of hills, tearing up and dispersing entire geological formations, and strewing the ocean-bottom with scattered debris. But this explanation had the disadvantage of being wofully unphilosophical and not very clearly orthodox. Such debacles did not appear to have ever taken place in any previous geologic era, and experience was against them. Besides, they did not account for some of the most evident characteristics of the pheno-

mena, such as the northern character of the formation, the long parallel striations of the rock surfaces, and the perching of huge boulders on lofty hills, often hundreds of miles distant from the parent rock. Geologists were completely at fault, and the boulder-clay remained a mystery for years.

When we consider the physical aspects of the countries where the question was studied, we cannot much wonder that the truth was so hard to find. In the midst of corn-fields and meadows, one cannot readily realize the fact that the spot where they stand has been the site of a wide-spread sea; and that where now villages and green lanes meet the eye, there once swam the porpoise and the whale, or monsters of a still earlier creation, unwieldy in bulk and uncouth in form. Such changes, however, must have been, for their traces meet us on every hand. We have the sea dashing against our shores, and there seems nothing at all improbable in the assertion that once it dashed against our hill-tops. No one, therefore, has any difficulty in giving such statements his implicit belief. But who could have dreamed that these fields, so warm and sunny, were once sealed in ice, and sunk beneath a sea that was cumbered with many a wandering iceberg? Who could have imagined, that down these glens, now carpeted with heath and harebell, the glacier worked its slow way amid the stillness of perpetual snow? And yet strange as it may seem, such is the true solution of the problem. The boulder-clay was formed during the slow submergence of our country beneath an icy sea, and the rock-surfaces owe their polished and striated appearance to the grating across them of sand and stones frozen into the bottom of vast icebergs, that drifted drearily from the north. That we may the better see how these results have been effected, let us glance for a little at the phenomena observable in northern latitudes at the present day.

Icebergs are formed in three principal ways :—1st, By glaciers descending to the shore, and being borne seawards by land-

winds; 2d, By river-ice packed during spring, when the upper reaches of the rivers begin to thaw; 3d, By coast-ice.

I. There is an upper stratum of the atmosphere characterized by intense cold, and called the region of perpetual snow. It covers the earth like a great arch, the two ends resting, one on the arctic, the other on the antarctic zone, while the centre, being about 16,000 feet above the sea,[1] rises directly over the tropics. Wherever a mountain is sufficiently lofty to pierce this upper stratum, its summit is covered with snow, and, as the snow never melts, it is plain that, from the accumulations of fresh snow-drifts, the mountain-tops, by gradually increasing in height and width, would become the supporting columns of vast hills of ice, which, breaking up at last from their weight and width, would roll down the mountain-sides and cover vast areas of country with a ruin and desolation more terrible than that of any avalanche. Olympus would really be superposed upon Ossa. By a beautiful arrangement this undue growth is prevented, so that the hill-tops never vary much in height above the sea. The cone of ice and snow which covers the higher part of the mountain, sends down into each of the diverging valleys a long sluggish stream of ice, with a motion so slow as to be almost imperceptible. These streams are called glaciers. As they creep down the ravines and gorges, blocks of rock detached by the frosts from the cliffs above, fall on the surface of the ice, and are slowly carried along with it. The bottom also of the glaciers is charged with sand, gravel, and mud, produced by the slow-crushing movement; large rocky masses become eventually worn down into fragments, and the whole surface of the hard rock below is traversed by long

[1] The average height of the snow-line within the tropics is 15,207 feet, but it varies according to the amount of land and sea adjacent, and other causes. Thus, among the Bolivian Andes, owing to the extensive radiation, and the ascending currents of air from the neighbouring plains and valleys, the line stands at a level of 18,000 feet, while, on mountains near Quito, that is, immediately on the equatorial line, the lowest level is 15,795.—See Mrs. Somerville's *Physical Geography*, 4th edit. p. 314.

parallel grooves and striæ in the direction of the glacier's course. Among the Alps, the lowest point to which the glacier descends is about 8500 feet. There the temperature gets too high to allow of its further progress, and so it slowly melts away, choking up the valleys with piles of rocky fragments called *moraines*, and giving rise to numerous muddy streams that traverse the valleys, uniting at length into great rivers such as the Rhone, which enters the Lake of Geneva turbid and discoloured with glacial mud.

In higher latitudes, where the lower limit of the snow-line descends to the level of the sea, the glaciers are often seen protruding from the shore, still laden with blocks that have been carried down from valleys far in the interior. The action of storms and tides is sufficient to detach large masses of the ice, which then floats off, and is often wafted for hundreds of miles into temperate regions, where it gradually melts away. Such floating islands are known as icebergs.

II. In climates such as that of Canada, where the winters are very severe, the rivers become solidly frozen over, and, if the frost be intense enough, a cake of ice forms at the bottom. In this way sand, mud, and rocky fragments strewing the banks or the channel of the stream, are firmly enclosed. When spring sets in, and the upper parts of the rivers begin to thaw, the swollen waters burst their wintry integuments, and the ice is then said to *pack*. Layer is pushed over layer, and mass heaped upon mass, until great floes are formed. These have often the most fantastic shapes, and are borne down by the current, dropping, as they go, the mud and boulders, with which they are charged, until they are stranded along some coast line, or melt away in mid-ocean.

III. But icebergs are also produced by the freezing of the water of the ocean. In high latitudes, this takes place when the temperature falls to 28·5° of Fahrenheit. The surface of the sea then parts with its saline ingredients, and takes the

form of a sheet of ice, which, by the addition of successive layers, augmented sometimes by snow-drifts, often reaches a height of from thirty to forty feet. On the approach of summer these ice-fields break up, crashing into fragments with a noise like the thundering of cannon. The disparted portions are then carried towards the equator by currents, and may be encountered by hundreds floating in open sea. Their first form is flat, but, as they travel on, they assume every variety of shape and size.

On the shores of brackish seas, such as the Baltic, or along a coast where the salt water is freshened by streams or snow-drifts from the land, sheets of ice also frequently form during severe frosts. Sand and boulders are thus frozen in, especially where a layer of ice has formed upon the sea-bottom.[1] The action of gales or of tides is sufficient to break up these masses, which are then either driven ashore and frozen in a fresh cake of ice, or blown away to sea. The bergs formed in this way have originally a low flat outline, and many extend as ice-fields over an area of many miles, while, at a later time, they may be seen towering precipitously as great hills, some 200 or 300 feet high.

Few sights in nature are more imposing than that of the huge, solitary iceberg, as, regardless alike of wind and tide, it steers its course across the face of the deep far away from land. Like one of the "Hrim-thursar," or Frost-giants of Scandinavian mythology,[2] it issues from the portals of the north armed

[1] I was informed by the late Mr. Hugh Miller, that a seam of shale abounding in liassic fossils, had been found intercalated among the boulder-clay beds in the vicinity of Eathie. He explained its occurrence there by supposing that it had formed a reef along a shore where ground-ice was forming; and so having been firmly frozen in, it was torn up on the breaking of the ice, and deposited at a distance among the mud at the sea-bottom.

[2] The account of the origin of these giants, as given in the prose *Edda*, is very graphic, and may be not inaptly quoted here:—"When the rivers that are called Elivagar had flowed far from their sources," replied Har, "the venom which they rolled along hardened, as does dross that runs from a furnace, and became ice. When the rivers

with great blocks of stone. Proudly it sails on. The waves that dash in foam against its sides shake not the strength of its crystal walls, nor tarnish the sheen of its emerald caves. Sleet and snow, storm and tempest, are its congenial elements. Night falls around, and the stars are reflected tremulously from a thousand peaks, and from the green depths of "caverns measureless to man." Dawn again arises, and the slant rays of the rising sun gleam brightly on every projecting crag and pinnacle, as the berg still floats steadily on ; yet, as it gains more southern latitudes, what could not be accomplished by the united fury of the waves, is slowly effected by the mildness of the climate. The floating island becomes gradually shrouded in mist and spume, streamlets everywhere trickle down its sides, and great crags ever and anon fall with a sullen plunge into the deep. The mass becoming top-heavy, reels over, exposing to light rocky fragments still firmly imbedded. These, as the ice around them gives way, are dropped one by one into the ocean, until at last the iceberg itself melts away, the mists are dispelled, and sunshine once more rests upon the dimpled face of the deep.[1] If, however, before this final dissipation, the wandering island should be stranded on some coast, desolation and gloom are spread over the country for leagues. The sun is obscured,

flowed no longer, and the ice stood still, the vapour arising from the venom gathered over it and froze to rime; and in this manner were formed in Ginnungagap many layers of congealed vapour, piled one over the other."—"That part of Ginnungagap," added Jafnhar, "that lies towards the north, was thus filled with heavy masses of gelid vapour and ice, whilst everywhere within were whirlwinds and fleeting mists. But the southern part of Ginnungagap was lighted by the sparks and flakes that flew into it from Muspellheim. . . . When the heated blast met the gelid vapour, it melted into drops, and, by the might of him who sent the heat, these drops quickened into life, and took a human semblance. The being thus formed was named Ymir, from whom descend the race of the Frost-giants (Hrim-thursar), as it is said in the Völuspá, 'From Vidolph came all witches; from Vilmeith all wizards; from Svarthöfdi all poison-seekers; and all giants from Ymir.'"—See Mallet's *Northern Antiquities*, edit. Bohn, p. 402.

[1] That beautiful expression of Æschylus occurs to me, so impossible adequately to clothe in English: *ἀνηριθμον γελασμα κυματων*. Who that has spent a calm summer day upon the sea, has not realized its force and delicate beauty?

and the air chilled; the crops will not ripen; and, to avoid the horrors of famine, the inhabitants are fain to seek some more genial locality until the ice shall have melted away; and months may elapse before they can return again to their villages.

The iceberg melts away, but not without leaving well-marked traces of its existence. If it disappear in mid-ocean, the mud and boulders, with which it was charged, are scattered athwart the sea-bottom. Blocks of stone may thus be carried across profound abysses, and deposited hundreds of miles from the parent hill; and it should be noticed, that this is the only way, so far as we know, in which such a thing could be effected. Great currents could sweep masses of rock down into deep gulfs, but could not sweep them up again, far less repeat this process for hundreds of miles. Such blocks could only be transported by being lifted up at the one place and set down at the other; and the only agent we know of, capable of carrying such a freight, is the iceberg. In this way, the bed of the sea in northern latitudes must be covered with a thick stratum of mud and sand, plentifully interspersed with boulders of all sizes, and its valleys must gradually be filled up as year by year the deposit goes on.

But this is not all. The visible portion of an iceberg is only about one-ninth part of the real bulk of the whole mass, so that if one be seen 100 feet high, its lowest peak may perhaps be away down 800 feet below the waves. Now it is easy to see that such a moving island will often grate across the summit and along the sides of sub-marine hills; and when the lower part of the berg is roughened over with earth and stones, the surface of the rock over which it passes will be torn up and dispersed, or smoothed and striated, while the boulders imbedded in the ice will be striated in turn.

But some icebergs have been seen rising 300 feet over the sea; and these, if their submarine portions sank to the maxi-

mum depth, must have reached the enormous total height of 2700 feet—that is, rather higher than the Cheviot Hills.[1] By such a mass, any rock or mountain-top existing 2400 feet below the surface of the ocean would be polished and grooved, and succeeding bergs depositing mud and boulders upon it, this

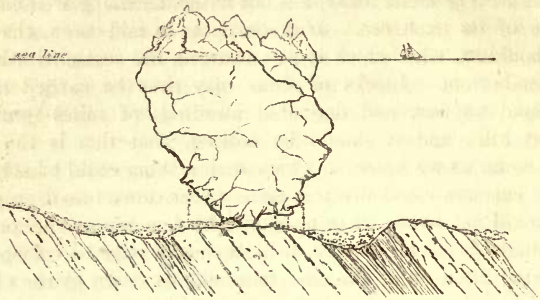

FIG. 1.—Iceberg grating along the sea-bottom and depositing mud and boulders.

smoothed surface might be covered up and suffer no change until the ocean-bed should be slowly upheaved to the light of day. In this way, submarine rock surfaces at all depths, from the coast line down to 2000 or 3000 feet, may be scratched and polished, and eventually entombed in mud.

And such has been the origin of the deep clay, which, with its included and accompanying boulders, covers so large a part of our country. When this arctic condition of things began, the land must have been slowly sinking beneath the sea; and so, as years rolled past, higher and yet higher zones of land were brought down to the sea-level, where floating ice, coming from the north-west, stranded upon the rocks, and scored them all

[1] In the *American Journal of Science* for 1843, p. 155, mention is made of an iceberg aground on the Great Bank of Newfoundland. The average depth of the water was about 500 feet, and the visible portion of the berg from 50 to 70 feet high, so that its total height must have been little short of 600 feet, of which only a *tenth* part remained above water.

over as it grated along. This period of submergence may have continued until even the highest peak of the Grampians disappeared, and, after suffering from the grinding action of ice-freighted rocks, eventually lay buried in mud far down beneath a wide expanse of sea, over which there voyaged whole argosies of bergs. When the process of elevation began, the action of waves and currents would tend greatly to modify the surface of the glacial deposit of mud and boulders, as the ocean-bed slowly rose to the level of the coast line. In some places the muddy envelope was removed, and the subjacent rock laid bare, all polished and grooved. In other localities, currents brought in a continual supply of sand, or washed off the boulder mud and sand, and then re-deposited them in irregular beds; hence resulted those local deposits of stratified sand and gravel so frequently to be seen resting over the boulder clay. At length, by degrees, the land emerged from the sea, yet glaciers still capped its hills and choked its valleys; but eventually a warmer and more genial climate arose, plants and animals, such as those at present amongst us, and some, such as the wolf, no longer extant, were ere long introduced; and eventually, as lord of the whole, man took his place upon the scene.[1]

It is pleasant to mark, when once the true solution of a difficulty is obtained, how all the discordant elements fall one by one into order, and how every new fact elicited tends to corroborate the conclusion. In some parts of the glacial beds, there occur regular deposits of shells which must have lived and died in the places where we find them. From ten to fifteen per cent. of them belong to species which are extinct, that is to say, have not been detected living in any sea. Some of them are still inhabitants of the waters around our coasts, but the large majority occur in the northern seas. They are emphati-

[1] The reader who wishes to enter more fully into the geological effects of icebergs, should consult the suggestive section on that subject in De la Beche's *Geological Observer*; also the *Principles* and *Visit to the United States* of Sir Charles Lyell, with the various authorities referred to by these writers.

cally northern shells, and get smaller in size and fewer in number as they proceed southward, till they disappear altogether. In like manner, the palm, on the other hand, is characteristically a tropical plant. It attains its fullest development in intertropical countries, getting stunted in its progress towards either pole, and ceasing to grow in the open air beyond the thirty-eighth parallel of latitude in the southern hemisphere, and the forty-fifth in the northern. So, too, the ivy, which in our country hangs out its glossy festoons in every woodland, and around the crumbling walls of abbey, and castle, and tower, is nursed in the drawing-rooms of St. Petersburg as a delicate and favourite exotic. In short, the laws which regulate the habitat of a plant or an animal are about as constant as those which determine its form. There are, indeed, exceptions to both. We may sometimes find a stray vulture from the shores of the Mediterranean gorging itself on sheep or lambs among the wolds of England,[1] just as we often see

> "A double cherry seeming parted,
> But yet an union in partition;"

or as we hear of a sheep with five legs, and a kid with two heads. But these exceptions, from their comparative rarity, only make the laws more evident. When, therefore, we find, in various parts of our country, beds of shells in such a state of preservation as to lead us to believe that the animals must have lived and died where their remains are now to be seen, we justly infer that the districts where they occur must at one period have been submerged. If the shells belong to fresh-water species, it is plain that they occur on the site of an old lake. If they are marine, we conclude that the localities where they are found—no matter how high above the sea—must formerly have stood greatly lower, so as to form the ocean bed. To proceed one step further. If the shells are of a southern type,

[1] Two of these birds (*Neopron pcenopterus*) are stated to have been seen near Kilve, in Somersetshire, in October 1825. One was shot, the other escaped.

that is, if they belong to species[1] which are known to exist only in warmer seas than our own, we pronounce that at a former period the latitudes of Great Britain must have enjoyed a more temperate and genial climate, so as to allow southern shells to have a wider range northwards. If, on the other hand, they are of an arctic or boreal type, we in the same way infer that our latitudes were once marked by a severer temperature than they now possess, so as to permit northern shells to range farther southwards. This reasoning is strictly correct, and the truth involved forms the basis of all inquiries into the former condition of the earth and its inhabitants.

The evidence furnished by the northern shells in the boulder-clay series is, accordingly, of the most unmistakable kind. These organisms tell us that at the time they lived our country lay sunk beneath a sea, such as that of Iceland and the North Cape, over which many an iceberg must have journeyed, and thus they corroborate our conclusions, derived independently from the deep clay and boulder beds and the striated rock-surfaces, as to the glacial origin of the boulder-clay.

[1] There is not a little difficulty in reasoning satisfactorily as to climatal conditions from the distribution of kindred forms. Even in a single genus there may be a wide range of geographical distribution, so that mere generic identity is not always a safe guide. Thus, the elephant now flourishes in tropical countries, but in the glacial period a long-haired species was abundant in the frozen north. I have above restricted myself entirely to *species* whose habits and geographical distribution are already sufficiently known.

CHAPTER III.

How the boulder came to be one—"Crag and tail"—Scenery of central Scotland: Edinburgh—"Crag and tail" formerly associated in its origin with the boulder-clay—This explanation erroneous—Denudation an old process—Its results—Illustration from the Mid-Lothian coal-field—The three Ross-shire hills—The Hebrides relics of an ancient land—Scenery of the western coast—Effects of the breakers—Denudation of the Secondary strata of the Hebrides—Preservative influence of trap-rocks—Lost species of the Hebrides—Illustration—Origin of the general denudation of the country—Illustrative action of streams—Denudation a very slow process—Many old land-surfaces may have been effaced—Varied aspect of the British Islands during a period of submergence—Illustration.

THE scratched and grooved surface of the boulder was produced when it was fast frozen in some iceberg, and driven gratingly across some submarine summit, or stranded on some rocky coast-line. But, from its rounded form, the stone had evidently undergone a long process of wear and tear previous to its glacial journey. Probably it had hitherto lain along a surf-beaten beach, where in the course of ages it had gradually been worn into its present rounded shape. But how came it there? It must originally have formed part of a flat sandstone bed, with many other beds piled above it. By what agency, then, was this great pile reduced to fragments?

The answer to these questions must be a somewhat lengthened one, for the subject relates not to a few beds of rock hastily broken up and dispersed, but to the physical changes of an entire country, carried on during a vast succession of geological periods.

A phenomenon, known familiarly as "crag and tail," has long been connected in its origin with the drift or boulder beds. Has my reader ever travelled through central Scotland? If so,

he must often have noticed the abrupt isolated form of many of the hills, presenting a mural front to the west, and a long sloping declivity to the east. From the great number of isolated hard trap-rocks in this region, the phenomenon is much better seen than in most other parts of the kingdom. There is, for instance, the castle rock of Stirling, with its beetling crag and castellated summit, which present so imposing a front to the west. Many other examples are seen along the line of the Edinburgh and Glasgow Railway. The range of hills south of Linlithgow, the singularly abrupt basalt of Binny Craig, the long rounded ridge of Ratho, the double-peaked crag of Dalmahoy, the broad undulation of woody Corstorphine, are all examples more or less marked. Edinburgh itself is an excellent illustration. The Calton Hill shows a steep front to the town, while its eastern side slopes away down to the sea. Arthur's Seat, in like manner, has a precipitous western face, and a gentle declivity eastward. The Castle rock, too, shoots up perpendicularly from the valley that girdles it on the north, west, and south, sinking away to the east in a long slope—

> " Whose ridgy back heaves to the sky,
> Piled deep and massy, close and high."

East-Lothian presents several well-marked instances; in particular, North Berwick Law and Traprain. A phenomenon so general must have had some general origin, and it was accordingly attributed to the same agency which produced the drift-clays and the striated rock-surfaces, when these were believed to be the results of great diluvial action. It would seem, however, that the phenomenon of crag and tail should not be associated with the boulder-clay. The latter is undoubtedly a newer Tertiary formation,[1] but the denudation [2] which produced

[1] The reader is referred to the table of the geological formations at the end of the volume for the relative position of the beds described.

[2] *Denudation* is a geological term used to denote the removal of rock by the wasting action of water, whereby the underlying mineral masses are *denuded* or laid bare.

crag and tail must have been going on long ere the Tertiary ages had begun. There is satisfactory evidence that large areas of our country were planed down at a greatly more ancient period than that of even the oldest of the Tertiary series. Thus, the whole area of the county of Sussex suffered a very extensive denudation during the later Secondary ages. The Hebrides had undergone a similar process previous to the deposition of the Lias and Oolite, and the Greywacke hills of south Scotland, previous to the formation of the Old Red Sandstone. There seems thus to have been a general and continuous process of degradation at work during a long succession of geological ages.

The results of this long-continued action are of the most startling kind. I have referred to the phenomenon of crag and tail as perhaps the most readily observable. We must not fail to remember that the crag which now stands up so prominently above the level of the surrounding country, at one period lay buried beneath an accumulation of sandstone, shale, or other strata, all of which have been carried away, so as to leave the harder rock in bold relief, with a portion of the less coherent strata sloping as a long tail from its eastern side. The crag, too, is often breached in many places, worn down at one end, rounded on the summit, and sometimes wellnigh ground away altogether, whilst in front there is invariably a deep hollow scooped out by the current when arrested by the abrupt cliff.

FIG. 2 —" Crag and tail."

In Fig. 2, *a* represents a crag of greenstone worn away and bared of the shales which once covered it; *b*, the sloping "tail" of softer strata, protected from abrasion by the resistance of the

trap-rock, and covered by a deep layer of drift, *d* ; *c* marks the hollow on the west side of the crag.

But when we come to measure the actual amount of material that has been carried away, we are lost in conjecture as to the vastness of the time which such a process must have occupied. For instance, the coal-bearing strata of Mid-Lothian must at one period have been connected with those of Linlithgow and Stirling. At a subsequent date, the western area subsided to form the Stirlingshire coal-basin, and the eastern area, in like manner, sank down to form the coal-basin of Mid-Lothian, while the intermediate portion stretched from east to west as a great arch, or, as it is termed geologically, an *anticlinal axis*. Now, the whole of this arch has been worn away,—not a vestige of it remains, and yet its upper or coal-bearing part was fully 3000 feet thick.[1]

Let us take a small portion of this district, and endeavour to calculate the amount of matter thus removed. The Pentland hills form a chain stretching from near Edinburgh for some fourteen miles southward, and having an average breadth of about two miles and a half. They are formed chiefly of felspathic trap-rocks, resting upon and interstratified with conglomerate apparently of Old Red age, which in turn lies upon vertical Silurian slates. Before the Carboniferous strata were thrown down by successive *faults*, they must have covered these hills completely to a depth of not less than 6000 feet.[2] From

[1] This remarkable example of denudation was first described by Mr. M'Laren, in his *Sketch of the Geology of Fife and the Lothians*, a work in which the author showed himself to be in advance of the science of his time.

[2] The actual depth of the Mid-Lothian coal-field, to the base of the carboniferous limestone, is rather more than 3000 feet. It is, perhaps, rather under than over the truth to allow 3000 feet for the total thickness of beds from the limestone to the conglomerate of Liberton, though, owing to the curved and contorted position of the strata from Edinburgh to Stirlingshire, it is impossible to obtain a measurement of their real thickness. I have attributed the isolation of the Falkirk and Mid-Lothian coal-fields to the effect of faults and general depressions of their areas. This was assuredly the case in the latter coal-field, and probably in the former also. The trap which occurs between them, though in great abundance, has certainly not acted as an elevating agent. It occurs in

this small area, therefore, stratified sandstones, shales, limestones, and coal, must have been removed to the enormous extent of one billion, eight hundred and fifty-four thousand, four hundred and sixty-four millions of cubic feet.

But, perhaps, the most striking instances of denudation in the British Islands are the three famous Ross-shire hills—Suil Veinn, Coul Mor, and Coul Bheig. They are formed of piles of sandstone beds like tiers of regular masonry, and reach a height of 3000 feet over the sea. The sandstone of which they are composed must once have formed a bed or set of beds fully 2000 feet thick, that covered the whole district for many miles around. Yet of this extensive deposit there now exist only a few isolated fragments. I have watched the sunshine and shadow of an autumn sky resting alternately on these strange pyramidal hills, as they towered in their giant proportions like the last remnants of a mighty rampart that had stood the brunt of a long siege, and, breached at last in many places, had been all but levelled to the ground. How long-continued and how potent must that agency have been which could cut down and disperse the massive barrier that flanked the western coast of Ross-shire to a height of 2000 feet!

The Hebrides are but the shattered relics of an old land that had its mountain-peaks and its glens, its streams and lakes, and may have nursed in its solitude the red-deer and the eagle, but was never trodden by the foot of man. A glance at the map is enough to convince us of this. We there see islands, and peninsulas, and promontories, and deep bays, and long-retiring inlets, as though the country had been submerged and only its higher points remained above water. The conviction is impressed more strongly upon us by a visit to these shores. We

beds among the strata, and, judging from the number of associated tufas, appears to have been to a considerable extent erupted while the lower carboniferous series was forming. Mr. M'Laren, in his excellent work, p. 100, states his opinion that the traps may have materially contributed to push up the coal strata. A careful and extended examination of the district has convinced me that this view is incorrect.

sail through the windings of one of the "sounds," and can scarcely believe that we are on the bosom of the salt sea. Hills rise on all sides, and the water, smooth as a polished mirror, shows so pure and limpid that in the sunshine we can see the white pebbles that strew its bed many fathoms down. The eastern shore is often abruptly interrupted by long-receding lochs edged round with lofty mountains, and thus, where we had looked to see a deep heathy glen, with, perchance, a white tree-shaded mansion in the far distance, and a few dun smoking cottages in front, we are surprised to catch a glimpse of the white sails of a yacht, or the darker canvas of the herring-boats. We sail on, and soon a sudden turn brings us abruptly to the mouth of the sound. A bold headland, studded around with rocky islets, rises perpendicularly from the sea, bleak and bare, without a bush or tree, or the faintest trace of the proximity of man. The broad swell of the Atlantic comes rolling in among these rocks, and breaks in foam against the grey cliffs overhead. In tempests, such a scene must be of the most terrific kind. Wo to the hapless vessel that is sucked into the vortex of these breakers, whose roar is sometimes heard at the distance of miles! Even in the calmest weather the white surf comes surging in, and a low sullen boom is ever reverberating along the shore. We see the harder rocks protruding far into the sea, and often pierced with long twilight caves, while the softer ones are worn into deep clefts, or hollowed out into open bays strewed over with shingle. The sunken rocks and islets, scarcely showing their tops above water, were all evidently at one time connected, for, as we recede from the shore, we can mark how the process of demolition goes on. There is first the projecting ness or promontory, wellnigh severed from the mainland, but still connected by a rude arch, through which the swell ever gurgles to and fro. Then, a little farther from the shore, a huge isolated crag, washed on all sides by the surge, raises its grey lichen-clothed summit. A short way beyond, there is the well-worn islet whose

surface shelters neither lichen nor sea-weed, but is ever wet with the dash of the waves. Further to the sea, the white gleam of the breakers marks the site of the sunken rock. Thus, in the space of a hundred yards, we may sometimes behold the progress of change from land to sea, and see before us a specimen of that action which slowly but yet steadily has narrowed and breached the outline of our western shores.[1]

If we attempt to trace the connexions of strata among the Hebrides, we shall be more fully impressed with the magnitude of the changes which have been effected. Thus the Lias and Oolite occur in patches along the shores of Mull, Morven, Ardnamurchan, Eigg, Skye, Raasay, and Applecross. But though now only in patches, these formations must once have extended over a considerable area, for they seem to form the under-rock of the whole of the northern part of Skye, and are seen in almost every lone island from Ardnamurchan Point to the Shiant Isles. These scattered portions, often many miles distant from each other, are the remnants of a great sheet of liassic and oolitic strata, now almost entirely swept away, and are extant from having been covered over with hard trap-rocks. But for these it may be doubted whether we should ever have known that corals once gleamed white along the shores of Skye, that the many-chambered ammonite swam over the site of the Coolin Hills, that the huge reptilian monsters of these ancient times, icthyosaurs and plesiosaurs, careered through the waters that laved the grey hills of Sleat, and that forests of zamia and cycas, and many other plants indicative of a warm climate, bloomed green and luxuriant along the site of that strange mist-clad cliff-line, that shoots up into the pinnacles of the Storr and Quiraing. It is curious to reflect, that the records of these peaceful scenes

[1] I have endeavoured to illustrate the process of denudation by a reference to breaker-action on the existing coast-line of the Hebrides; but a strong current must have materially increased the force of the ancient waves, and produced abrasion to some depth below them.

have been preserved to us by the devastating eruptions of volcanic forces; that the old lava-streams which spread death through the waters along whose bed they travelled, have yet been the means of protecting the districts which they wasted, while those parts where they did not reach have been long since swept away. It is allowable to believe, that in the portions of liassic strata which have been destroyed there existed the remains of not a few species, perhaps some genera, to be found nowhere else, and of whose former existence there is now, by consequence, no trace. In the small island of Pabba—a relic of the Scottish Lias—I found thirty-one species, of which Dr. Wright has pronounced four to be new.[1] A subsequent visit to the adjacent island of Raasay has increased the list. In short, every patch of these Secondary rocks, if thoroughly explored, might be found to yield its peculiar organisms. And in the far larger area that has been carried away there existed, doubtless, many more. We are accustomed to see individuals perish and their remains crumble away, but the species still holds on. In the stratified portion of the earth's crust, however, we mark how not merely individuals have perished, but whole genera and species; but of these the remains are still before us in the rocks; we can study their forms, and, from a comparison with recent species and genera, can arrive at some idea of their nature and functions. In this way, we are able to picture the various conditions of the earth when these organisms lived in succession upon its surface. Yet, we may readily conjecture, that in ancient eras many tribes and genera of plants and animals lived for ages, and then passed away without leaving any record of their existence. Many circumstances might concur to prevent the preservation of their remains. The species of the Hebrides were preserved in the usual manner, but the cemetery in which their remains were entombed has been washed away, and they can be seen nowhere else. It is as if on some isolated country there had lived a race of men,

[1] *Quart. Jour. Geol. Soc.*, vol. xiv. p. 26.

tall Patagonians, or swarthy Hottentots, or diminutive Laplanders, with a civilisation of their own; owing to some change of climate the race gradually dwindled down until it died out; eventually, too, the land settled down beneath the sea with all its ruined cities and villages, which, as they reached in succession the level of the waves, were torn up and dispersed, and other races at last voyaged over the site of that old land, dreaming not, that in bygone years fellow-mortals of an extinct type had pastured their herds where now there rolled a wide-spread sea.

But to return. We have seen that the long-continued action of the sea has been sufficient to breach and waste away the existing coast-line of western Scotland. When, therefore, such results are produced by so ordinary a cause, need we go to seek the agency of great debacles to explain the denudation of other parts of the country? It is known that at great depths currents have little effect upon the rocks which they traverse, and that their action is greater as it nears the surface. To account for the phenomena of crag and tail, and the general denudation of the country, we may suppose the land to have been often submerged and re-elevated. As hill after hill rose towards or sank below the sea-level, it would be assailed by a strong current that flowed from the west and north-west, until, in its slow upward or downward progress, it got beyond the reach of the denuding agencies. In this way the general contour of the land would be greatly though very gradually changed. Hills of sandstone, or other material of feeble resistance, would be swept away, the harder trap-rocks would stand up bared of the strata which once covered them, deep hollows would be excavated in front of all the more prominent eminences, and long declivities would be left behind them.—(See Fig. 2.)

If my reader has ever visited the channel of a mountain-torrent—

> "Imbres
> Quem super notas aluere ripas"—

he must have noticed an exact counterpart to these appearances. When the waters have subsided, the overflowed parts are seen to be covered in many places with sand. Wherever a pebble occurs along the surface of this sand, it has invariably a hollow before it on the side facing the direction whence the stream is flowing, and a long tail of sand pointing down the channel. If we watch the motion of the water along its bed, the denuding agency may be seen actively at work. Every pebble that protrudes above the shallow streamlet arrests the course of the current, which is then diverted in three directions. One part turns off to the right hand of the pebble, and cuts away the sand from its flank ; another part strikes off to the left, and removes the sand from that side ; while a middle part descends in front of the pebble, and, by a kind of circular or gyratory movement, scoops out a hollow in the sand in front. Behind the pebble the water is pretty still, so that the sand remains undisturbed, and is further increased by the accumulation above it of sediment swept round by the lateral currents. Now, in place of the supposed stream, let us substitute the ocean with its westerly current—for the pebble, a great trap-hill—for the sand, easily friable shales and sandstones, and we have exactly the condition of things which produced crag and tail.

This process of destruction must have been in progress during many geological ages. We may suppose, that in that time the land often changed level, sometimes rising far above the sea, and sometimes sinking deep below it. We can well believe that the surface would often be covered with vegetation ; that plants, widely differing from those which are now indigenous, clothed its hill-sides and shaded its valleys ; and that animals of long extinct forms roamed over its plains or prowled amid its forests. When the country, in the lapse of centuries, sank beneath the sea-level, all trace of these scenes would eventually be effaced. The westerly currents would soon recommence the process of degradation, uprooting the forests, devastating the

plains, wearing down the hills, and scooping out the valleys; and so, when the ocean-bed, in the course of ages, became again dry land, it would arise "another and yet the same." The little valley, where once, perchance, the mastodon used to rest his massive bulk amid a rich growth of ferns, shaded by the thick umbrage of coniferous trees, would emerge a deep glen with bare and barren rocks on either side; the site of the hill whereon herds of the gazelle-like anoplothere were wont to browse, might reappear a level plain; the low-browed rock, under whose shadow the ungraceful palæothere used of old to rest from the heat of the noon-tide sun, might emerge a beetling crag shooting up several hundred feet over the valley. It is by this repeated elevation and submergence, carried on for many ages, that our country has acquired its present configuration.

We can easily picture to ourselves the appearance which the British Islands would thus at different periods present. At one time, nearly the whole of England would be under water, with, however, a few islands representing the higher peaks of Cornwall; others scattered over the site of the West Riding of Yorkshire; and a hilly tract of land over what is now Wales. Scotland must have existed in a sorely mutilated state. A thick-set archipelago would represent the Cheviot Hills, and the country south of the Forth and the Clyde; north of which there would intervene a broad strait, with a comparatively large area of undulating land beyond, stretching across what is now the area of the Grampian Hills. A narrow fiord would run along the site of the Caledonian Canal, cutting the country into two parts, and running far into it on either side as deep lochs and bays. I have had such a condition of things vividly recalled when on the summit of a lofty hill in early morning, while the mists were still floating over the lower grounds, and only the higher hill-tops, like so many islands, rose above the sea of cloud. It was not a little interesting to cast the eye athwart this changing

scene, and mark how each well-known peak and eminence looked when deprived of its broad sweep of base. What before had always seemed an abrupt precipitous summit, now took the form of a lonely rock or deep-sea stack, that might have served as a haunt for the gull and the gannet. The long swelling hill rose above the mist as a low undulating island, treeless and barren. It was easy to think of that wide expanse of mist as the veritable domain of ocean, to picture the time when these were veritable islands lashed by the surge, and to conjure up visions of ice-floes drifting through the narrows, or stranding on the rocks, amid a scene of wide-spread nakedness and desolation.

CHAPTER IV.

Interior of the boulder—Wide intervals of Geology—Illustration—Long interval between the formation of the boulder as part of a sand-bed, and its striation by glacial action—Sketch of the intervening ages—The boulder a Lower Carboniferous rock—Cycles of the astronomer and the geologist contrasted—Illustration—Plants shown by the boulder once grew green on land—Traces of that ancient land—Its seas, shores, forests, and lakes, all productive of material aids to our comfort and power—Plants of the Carboniferous era—Ferns—Tree-ferns—Calamites—Asterophyllites—Lepidodendron—Lepidostrobus—Stigmaria—Scene in a ruined palace—Sigillaria—Coniferæ, Cycadeæ—Antholites, the oldest known flower—Grade of the Carboniferous flora—Its resemblance to that of New Zealand.

I HAVE likened the boulder to an old volume of the middle ages encased in a modern binding. We have looked a little into the mechanism and history of the boards; in other words, we have gone over the history of the scratched surface of the boulder, of the clays and sands around it, and of that still earlier cycle of denudation whereof the rock itself is probably a relic. Before proceeding to open the volume itself, it will be well that we clearly mark the wide interval in time between the ages represented by the surface-striation and those indicated by the interior of the boulder. When we proceed from the groovings on the outside to the plants within, we pass, to be sure, over scarcely an inch of space, but we make a leap over untold millenniums in point of time. It is as if we had laid our hands on a volume of history which had by some misfortune found its way into the nursery. The first page that catches our eye relates the battle of the Reform Bill, and, on turning the previous leaf, we find ourselves with Boadicea and her woad-coloured soldiery. Now, if one utterly ignorant of the chronology of the country were to be told that the volume

related solely to one people, he would at once see from the manners and customs delineated, that the two pages referred to very different states of civilisation, and consequently to widely-separated periods. But he could give no account of how long an interval might have elapsed between the time when London had its inhabitants massacred by Boadicea, and the time when another generation of them was excited by the tardiness of King William IV. He could form no conjecture as to what events might have happened in the meanwhile. The interval might be a century or twenty centuries, wherein the city might have been burnt down fifty times. Clearly, if he wished to make himself acquainted with the intervening history, he would have to betake himself to an unmutilated volume.

And just so is it with our boulder. We can easily believe, merely from looking at it as it lies on its clayey bed, that a long time must have elapsed between the time of its formation as part of a sandstone bed, and the period of its transportation and striation by an iceberg. The sand of which it is formed must have been washed down by currents, and other sediment would settle down over it. It would take some time to acquire its present hardness and solidity, while, in long subsequent times, after being broken up and well-rounded by breaker or current action, it may have lain on some old coast-line for centuries before it was finally frozen into an ice-floe, and so freighted to a distance. But the stone, with all its stories of the olden time, can tell us nothing of this intervening period. It leads us from a dreary frozen sea at once into a land of tropical luxuriance, and so, if we desire to know anything of the missing portion of the chronology, we must seek it elsewhere.

The Boulder-clay is one of the latest of geologic periods.[1] Beyond it we get into Tertiary times, and learn from the caves

[1] For the names and succession of the rocks of which the known part of the earth's crust is composed, see the Table at the end of the volume.

of Yorkshire how elephants, hyenas, rhinoceroses, hippopotami, bears, and wolves, prowled over the rich valleys; while, from the quarries of the Isle of Wight, we see how at an earlier time herds of uncouth palæotheres and slimly-built anoplotheres browsed the plains of Old England. Beyond the Tertiary ages come those of the Chalk, with its ocean that swarmed with sea-urchins, terebratulæ, pectens, sponges, and many other forms. Then arises the era of the Wealden, with its bosky land haunted by the unwieldy iguanodon; the Oolite, with its land rich in a coniferous flora, and tenanted by a race of small marsupial animals, and its seas abounding in corals, encrinites of many a form, cidares, cuttle-fishes, and ammonites. Further back still, come the times of the Lias, that strange era in the history of our country, when reptiles huger than those of the Nile swam the seas, and sped on wings through the air. Then come the times of the Trias, when a vegetation still further removed from existing types clothed the land, and frogs large as oxen waddled along the shores. Then the times of the Permian, with its deep sea tenanted by a meagre list of corals and shells, and by a type of fishes that was slowly passing away. We arrive at last at the Coal or Carboniferous period, to the older ages of which our boulder belongs.

These eras may have been some longer, some shorter, but each had a duration which, when tried by human standards, must be regarded as immensely protracted. The cycles of astronomy are very vast, yet I have often thought that the cycles of geology, though probably of much less duration, impress us more forcibly with the antiquity of our planet. The astronomer tells us of light that has taken two millions of years to reach our earth, and of nebulæ that are millions upon millions of miles distant, but these numbers are so vast that we cannot bring ourselves to realize them. We *know* that there is a great difference between two millions and ten millions, but we cannot fully *appreciate* it, and so the

periods of the astronomer, beyond a certain point, cease adequately to impress us. So long as they can be easily contrasted with our own standards of comparison, they have their full force; but after that, every additional million, or ten millions, or ten hundred millions, produces only a confused and bewildered sense of immensity, and the comparative amount of each addition fails to be realized. Will my reader forgive a homely illustration:—Some years ago, I stood at the pier-head of one of our smaller sea-port towns, and watched the sun as it sullenly sank behind the outline of the opposite hills. The breadth of the channel, in the direction of sunset, was several miles, but in the flush of evening one fancied he could almost have thrown a stone across. The water lay unruffled by a ripple, and reflected all the thousand varying tints that lighted up the sky. The harbour, that had been a busy scene all evening, began to grow less noisy, as one by one the herring-boats pushed out to sea. I found it not a little interesting to mark, as the boats gained the open firth, how the opposite coast-line gradually seemed to recede. The farther the dark sails withdrew, the more remote did the adjacent shores appear, until, as the last tinge of glory faded from the clouds, and a cold grey tint settled down over the landscape, the hills lay deep in shade and stretched away in the twilight as a dark and distant land from whose valleys there rose troops of stars. The coast-line, as seen in early evening, reminded me of the periods of the astronomer; as seen in early night, it reminded me of the periods of the geologist. We fail to appreciate the real duration of astronomical cycles, because they are presented to us each as one vast period. They are not subdivided into intervals, and contain no succession of events, by means of which, as by milestones, we might estimate their extent; and so their unvaried continuity tends to diminish the impression of their vastness, just as the firth, without any islet or vessel on its surface,

seemed greatly narrower than it really was. For it is with time as it is with space—the eye cannot abstractly estimate distance, nor can the mind estimate duration. In either case, the process must be conducted by a comparison with known standards. The geological periods exemplify the same rule. They may not be greater, perhaps not so great, as those revealed by astronomy, yet their vastness impresses us more, because we can trace out their history, and see how step by step they progressed. Thus, that the interval between the boulder-clay and the coal-measures was immense, we learn from the records of many successive ages that intervened, in the same way that one began to perceive the real breadth of the firth, by resting his eye on the succession of intervening herring-boats. In the former case, the mind has ever and anon a sure footing on which to pause in gauging bygone eternity; in the latter, the eye had likewise a succession of points on which to rest in measuring distance. Or, to return to a former illustration: Boadicea lived eighteen hundred years ago, but who does not feel that the last nine hundred years look a great deal longer than the first? The one set has few marked incidents to fix the thoughts; the other is replete with those of the most momentous kind. In the one, we have a meagre list of conquerors and kings, from Julius Cæsar down to Athelstan; in the other, events crowd upon us from the waning of the Saxon power down through the rising glory of our country to the present plenitude of its power and greatness. The early centuries, like the cycles of the astronomer, pass through our mind rather as one continuous period; the later centuries, like the cycles of the geologist, arrest our thoughts by a succession of minor periods, and hence the idea of duration is more vividly suggested by the diversified events of the one series, than by the comparatively unbroken continuity of the other.

Let us now open the volume and try to decipher the strange

legends which it contains. On removing some of the upper layers of the boulder, I found, as I have said, well-preserved remains of several kinds of plants. One of them was ribbed longitudinally, with transverse notches every three or four inches, as though a number of slender threads had been stretched along a rod, and tied tightly to it at regular intervals. Another, sorely mutilated, was pitted all over somewhat after the fashion in which the confectioner punctures his biscuits. A third had a more regular pattern, being prettily fretted with small lozenge-shaped prominences that wound spirally round the stalk. Other plants seemed to be present, but in a very bad state of preservation. They were all jumbled together and converted into a black coaly substance, in which no structure could be discerned.

These plants assuredly once grew green upon the land; but where now is that land on which they flourished? Had it hills and valleys, rivers and lakes, such as diversify our country? Was it tenanted by sentient beings, and, if so, what were their forms? Did insects hum their way through the air, and cattle browse on the plains, and fish gambol in the rivers? Was the land shaded with forests, dark and rugged like those of Norway, or fragrant as the orange-groves of Spain? What, in fine, were its peculiar features, and how far did its scenery resemble that of any country of the present day?

That old land has not entirely disappeared. Traces of it are found pretty extensively in South Wales, in Staffordshire, around Newcastle, and through central Scotland. Strange as it may seem, its forests are still standing in many places. The fishes that disported in its lakes, the insects that fluttered amid its woods, and the lizards that crawled among its herbage, are still in part preserved to us. Nay, more; we may sometimes see the sea-beaches of that ancient land pitted with rain-drops, and roughened with ripple-marks, as freshly as if the shower had

fallen and the tide had flowed only yesterday. The peasants along the Bay of Naples gathered grapes from the flanks of Vesuvius for well-nigh seventeen centuries, before it was ascertained that they daily walked over the site of buried cities, with temples, theatres, and private houses still erect. It was many more centuries ere the people of Great Britain discovered that not a few of their villages and towns stood on the site of buried forests, and lakes, and seas. We have now, however, become aware of the fact, and are making good use of it. We dig into the earth and exhume these old forests to supply us with light and fuel; we quarry into the ripple-marked shores which fringed that old land, and build our houses with the hardened sand; we calcine the ferruginous mud that gathered in its swampy hollows, and extract therefrom our most faithful ally both in peace and war—metallic iron; we burn the delicate corals and shells and lily-like zoophytes which lived in the sea of that far-distant era, to enable us to smelt our iron, to build our houses, and manure our fields; in short, every year we are discovering some new and valuable material in the productions of that period, or finding out some new use which can be made of the substances already known. A more than ordinary interest, therefore, attaches to the history of the land and sea which have furnished us with so many aids to comfort as well as power; and we shall find, as we go on, that that history is a very curious one.

I shall describe some of the more common plants and animals of the period, that we may be able, in some measure, to look back through the ages of the past, and see how these plants would appear when they cast their broad shadow over river and lake, and how these animals would have seemed to human eye in the twilight of the forest, in the sluggish flow of the river, and in the stagnant waters of the lagoon.

The *Flora*, or vegetation of the Carboniferous era, differed

widely from any that now exists. With the exception of the highest or exogenous class, it possessed representatives of all the existing classes of the botanic scale, but in very strange proportions. The number of species of carboniferous plants already found in Great Britain amounts to about three hundred, amongst which the ferns are especially abundant. Some of them seem to have been low-growing plants, like the bracken of our hill-sides, but others must have shot up to the height of forest trees. We can recognise a few coniferous and cycadaceous plants, a good many stems resembling the "horse-tail" of our marshy grounds, and some of large size akin to the creeping club-moss of our heaths; but there are still many to which there exist no living analogues.

When we examine the roof of a coal-pit, or split open plates of shale in a quarry of the coal-measures, we are struck with the similarity which the ferns in the stone bear to those among our woods and hills. One of the most common, and, at the same time, most elegant forms, is the *Sphenopteris* or wedge-leaved fern, of which a large list of species is known. One of them (*S. crenata*) had a strong stem, from which there sprung straight tapering branches richly dight with leaflets. The leaflets—somewhat like minute oak-leaves—were ranged like those of our modern ferns, along two sides of the stalk, in alternate order, and tapered gently away to its outer extremity. The effect of the whole is singularly rich, and one can well believe that a garland of this ancient fern would have wreathed as gracefully around a victor's brow as the parsley of Nemea or the laurel-leaves of Delphi.

Another plant of the same genus (*S. affinis*, Fig. 3) has leaflets like the petals of the meadow-daisy, arranged in clusters along its slim diverging stalks. From a collection and comparison of many specimens, the late lamented Hugh Miller was enabled to make a drawing of this fern as it must have appeared when it waved green along the old carboniferous hill-sides. I enjoyed

the privilege of going over these specimens with him, and marked how, under a master-hand, piece by piece fell into its proper place, and yielded up its evidence. His restoration,

FIG. 3.—Sphenopteris affinis.

which forms the frontispiece to his last work, is a very beautiful one, and it is as true as it is beautiful.

The *Pecopteris* (Fig. 4, *P. heterophylla*) or comb-fern, is so called from its stiff thick leaflets being in some species arranged along the stalk like the teeth along the centre of a comb. Of all the plants of the coal-measures this is the one that approaches

most closely to living nature. It appears to be almost identical with the *pteris*, of which one species is well known as the bracken of our hill-sides. Dr. Hooker figures together a frond of a New Zealand species (*P. esculenta*) and a fossil frond from the Newcastle pits. They are so similar as to be easily mistaken at first sight for drawings of the same plant.[1] The *Neuropteris* (as *N. gigantea*, Fig. 6) or nerve-leaved fern, is remarkable for its strongly-defined venation. It is scarcely, perhaps, so elegant in its outline as the *sphenopteris*, or some of the other ferns. Its

FIG. 4.—Pecopteris.

FIG. 5.—Cyclopteris.

FIG. 6.—Neuropteris.

leaflets are large and thick, with an oblong or rounded form, and arranged either singly along the frond stem, or along secondary foot-stalks, which diverge from the main stem. Of the latter kind, some of the species have a good deal of resemblance to our *Osmunda regalis* or royal fern. A species of the former class (*N. cordata*) might readily enough be mistaken for the young leaves of the *Scolopendrium* or hart's-tongue, which hangs out its glossy green amid the gloom of dank and dripping rocks. There are, besides, several other genera of ferns in the Carboniferous strata, such as the *Cyclopteris* (*C. dilatata*, Fig. 5) or round-leaved fern, and the *Odontopteris* or tooth-fern. Most of these seem to have been lowly plants, like the ferns of

[1] Hooker, *Mem. Geol. Surv.* vol. ii. part ii. p. 400.

our own country. But there was another class to which no analogue can be shown in Europe. They rose high over their humbler congeners as lofty trees, and must be studied by a reference to the existing tree-ferns of intertropical countries.

FIG. 7.—Living Tree-fern.

Tree-ferns flourish in warm climates, and are met with in Brazil, the East and West Indies, New Zealand, &c. They rise sometimes to the height of fifty or sixty feet, with a long

tapering stem surmounted by a dense crown of graceful fronds, and might easily be mistaken at a little distance for palms. All the known species belong to the same division (*Polypodiaceæ*) with the common polypodium of our road-sides. In some genera, as the *alsophila* of the East Indies, the trunk is ribbed by long creeping branches, or rather rootlets, which descend to the soil, giving the tree somewhat of the appearance so often seen in old woods, where venerable fir-trees have been firmly encased by the bearded stems of the ivy. Another genus, the *Cyathea*, has its stem covered with oblong scars where leaves were attached, and a circle of rich outspread fronds surmounts its summit. One of the coal-measure tree-ferns seems to have resembled this recent type. It is named the *Caulopteris* or stalk-fern, and had a thick stem picturesquely roughened by irregular oblong leaf-scars, that wound spirally from its base to its point. No specimen has hitherto been found showing the fronds in connexion with the stem, so that we are still ignorant of the kind of foliage exhibited by this ancient tree. There can be no doubt, however, that it was crowned with a large tuft of boughs that cast their shadow over the sward below, and we may, perhaps, believe that some of the numerous detached ferns found in the shales of the coal-series, once formed part of this lofty coronal.

An important section of the carboniferous plants is embraced under the generic name of *Calamites.* They had smooth jointed stems, like reeds, and terminated beneath in an obtuse curved point (Fig. 8), from which there sprang broad leaflets or rather rootlets. After many years of research our knowledge of these plants is still very scanty. Some of them have exhibited a highly-organized internal structure, from which it appears that they consisted—first, of a soft central cellular pith ; second, of a thick layer of woody tissue ; and third, an external cylinder of strong bark, ribbed longitudinally, and furrowed transversely.

They have been ranked with the common horse-tail of our ponds, but they would rather appear to belong to a higher family. The breadth of the stem is very various, some specimens being a foot or more in diameter, others scarcely half an

FIG. 8.—Terminal portion of a calamite stem.

inch. From the discoveries of Professor Williamson and Mr. Binny of Manchester, it seems not unlikely that what we call calamites may be really the inner core of a plant not yet named, just as a set of fossils were long called *sternbergiæ*, before they were discovered to be really the pith of coniferous trees. With regard to the branches of the calamites, Brongniart's conjecture may be true, that they exist among the group of plants called *asterophyllites.* It is not unlikely that many dissimilar plants have been grouped together as calamites, and, on the other

hand, that plants allied to the typical species have been thrown into separate genera. For it requires but a slight acquaintance with the vegetable kingdom to know how many forms analogous parts of the same plant may assume, and how impossible it would often be to guess the real relationship of such varieties if they were not found growing together on one plant.

A remarkably graceful class of the coal-plants are known as *asterophyllites.* They had slim fluted and jointed stalks, apparently of humble growth. From each of the joints there sprang two thin opposite branches with stellate clusters of leaflets arranged round them at equal distances. If the reader will take a young rush-stalk, and string along it a number of the flowers of the little star-wort, keeping them a little distance apart, he may form some idea of the appearance of a single branch of the star-bearing *asterophyllite.* Some of the plants embraced under this genus are conjectured to have been aquatic, spreading out their clusters of leaflets in the green sluggish water of stagnant pools ; but many of them are evidently

FIG. 9.*

* The fossil given in Fig. 9 is named by Lindley (*Foss. Flo.* t. 15, 16), *Calamites nodosus.* He admits, however, that it was not found in actual contact with a calamite stem. It has exactly the contour of an asterophyllite, and might, perhaps, be referred to that genus. It is inserted here that the reader may see the general form of the asterophyllites, and the close relationship that subsists between these plants and the calamites.

related to the calamites, and may possibly have formed part of these plants.

Whoever has rambled much in a coal-country, scrambling through briars and brambles in old quarries, or threading his way among the rocks of river-courses, must often have noticed, on the exposed surface of sandstone blocks, dark ribbon-like bands fretted over with little diamond-shaped knobs. They are so common in some districts, that you can scarcely light upon a piece of sandstone which does not show one or more. They belong to a carboniferous plant known as *lepidodendron* (Fig. 10) or scaly tree, from the peculiar style of ornamentation which adorned its bark. Its structure and affinities have puzzled botanists not a little. A well-preserved specimen reminds one of the appearance presented by a twig of the Scotch fir, when stripped of its green spiky leaflets. The scars thus left at the base of the leaflets are of a wedge-like form, and run spirally up the branch in a manner very like those on the branches of lepidodendron ; and it was accordingly supposed at one time that the latter plant belonged, or at least was allied, to the conifers. But the branches of lepidodendron possessed a peculiarity that is shared in by none of our present coniferous trees. They were what botanists call *dichotomous*,—that is, they subdivided into two equal branches, these again into other two, and so on. Their internal texture,[1] too, differed from that of any known conifer. The only tribe of existing plants with which the lepidodendron seems to bear comparison, are the *Lycopodiaceæ*, or club-mosses, of which we have several species in the moor-lands of our own country. They are low trailing plants, with moss-like scaly branches, bearing at their ends shaggy little tufts,—whence the popular name of the genus. In warmer climates, they are both more numerous and attain a larger size, sometimes standing erect to about the height of an ordinary gooseberry-bush. But though the lepidodendron appears to

[1] See Hooker, *Mem. Geol. Surv.* vol. ii. part ii. p. 436.

have been allied to these plants in structure, it greatly differed from them in dimensions. The club-mosses of the coal-measures shot up as goodly trees, measuring fifty feet and upwards in height, and sometimes nearly five in diameter. Their general

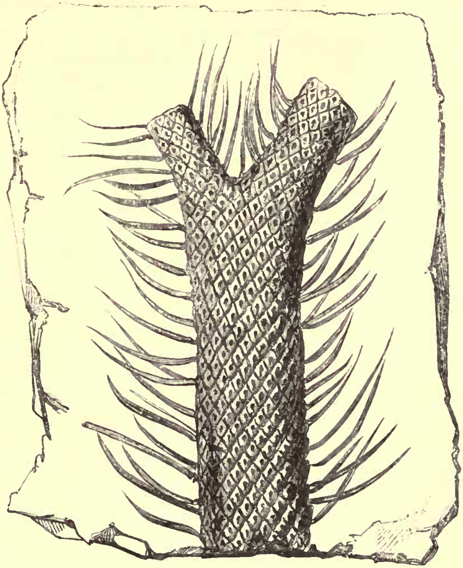

FIG 10.—Lepidodendron Sternbergii.

effect must have been eminently picturesque. A shaggy covering of green spiky leaflets bristled over their multitudinous pendant boughs; and where on the older stems these leaflets had decayed and dropped off, the outer bark was laid bare, fretted over with rows of diamond-shaped or oval scars, separated by waving lines of ridge or furrow, that wound spirally round the stem. From not a few of the branches there sprung oblong hirsute

cones called *lepidostrobi* (Fig. 11), which bore the sporangia, or seed-cases. These cones are of frequent occurrence in the shales of the coal-measures, and may be readily recognised. They had a central axis round which the oblong sporangia were built, the whole being protected externally by a thick covering of pointed scales, imbricated like the cone of the Scotch fir. The leaflets of lepidodendron, called *lepidophylla*, were broader than those of the Scotch fir, and had a stout mid-rib, which must have given them a rigidity like that of the araucarian pine—a plant they may also have resembled in the dark glossy green of its leaves.

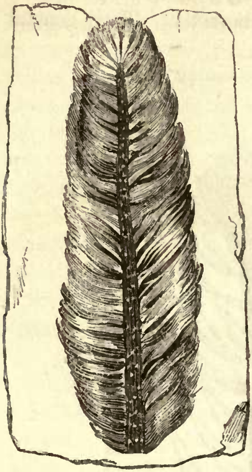

Fig. 11.—Lepidostrobus.

Of all the common coal-measure plants, there is perhaps none so abundant as that known by the name of *stigmaria*, or punctured-stem. It is found spreading out its rootlets for several yards in beds of shale and under-clay, and sometimes even limestone,[1] while, in many sandstones, fragments of its blackened stems lie as thickly strewn as twigs among the woods in autumn. I have said that several of the plants above described have greatly puzzled botanists. None of them, perhaps, has given rise to so much conjecture and variety of opinion as the stigmaria. The history of the discussion regarding its nature and affinities, would be not a little interesting as an illustration of the slow hindered progress often attendant on the researches of science, and an instance of how a few simple facts are some-

[1] The fresh-water limestone of Mid-Calder abounds in long trailing stems and rootlets of stigmaria, mingled with other terrestrial plants, and shells of *cyprides*.

times enough to overturn the most plausible theories and probable conjectures. Many thousands of specimens had been examined ere one was found that revealed the true nature of the stigmaria. It was by some imagined to be a soft succulent marshy plant, consisting of a number of long branches radiating from a sort of soft disk, like spokes from the centre of a wheel. Analogies were suggested with dicotyledonous tribes, as the *cacti* and *euphorbiæ*, though it was at the same time admitted that the ancient plant presented appearances which seemed very anomalous.

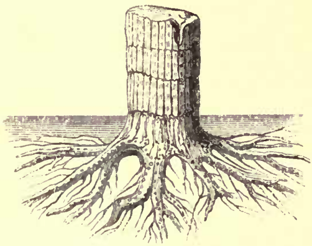

FIG. 12.—Stigmaria rootlets springing from Sigillaria stem.

In the course of an extensive survey of the coal-field of South Wales, Mr. (now Sir William) Logan ascertained the important fact, that each coal-seam is underlaid by a bed of clay, in which the stems of stigmaria, branching freely in all directions, may be traced to the distance of many feet or even yards. They were recognised as undoubtedly occupying the site on which they grew, and consequently each coal-seam was held to rest upon an ancient soil. Some years afterwards, in making a cutting for the Lancaster and Bolton Railway, several upright massive stems belonging to a plant called *sigillaria*, were found to pass downwards into true stigmaria stems (Fig. 12). There could be no doubt that they were different parts of one and the same plant. This fact has since been abundantly demonstrated from the Nova Scotia coal-field. Many sigillariæ have been found there passing down into the fire-clay below, where they branch out horizontally as true stigmariæ. It is evident, therefore, that the stigmaria was the under-ground portion of a plant, which, judging from the nature of the soil, and the free mode in

which the tender rootlets branched off, appears to have lived in aquatic or marshy stations.

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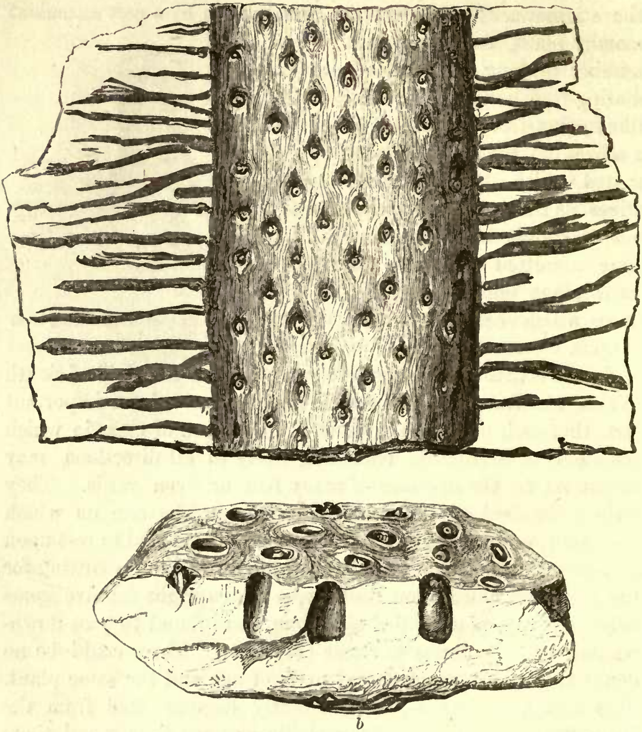

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FIG. 13.—Stigmaria.

The stigmaria is too well marked to be readily confounded with any other coal-measure plant. It had a rounded stem, seldom more than four or five inches across, which was marked

by a series of circular tubercules with a puncture in the centre, arranged in spiral lines round the stem. Each of these tubercules is surrounded, in ordinary specimens, by a circular depression,[1] and the whole plant (if one may use the comparison) looks as if it had been smitten with small-pox. From the hollow in the centre of each protuberance, there shot out a long round rootlet, formerly thought to be a leaf, and since the tubercules are pretty thickly set, the stigmaria must have had a somewhat hirsute appearance as it crept through the mud. It would resemble a thick bearded stem of ivy, save that the fibres, instead of running up two sides, were clustered all round it. Along the centre of the root, there ran a woody pith of a harder and more enduring texture than the surrounding part of the plant. The space between the outer tuberculed rind and the inner pith, seems to have been of a soft cellular nature, and to have decayed first, for the pith is sometimes hollow, and may not unfrequently be seen at a distance from the centre, and almost at the outer bark—a circumstance that seems only explicable on the supposition, that while the surrounding portions were decaying, the firmer pith altered its position in the hollow stem, sinking to the lower side, if the plant lay prostrate, and that it did not itself begin to decay until the interior of the stem had been at least partially filled up with sand or mud, or fossilized by the infiltration of lime. From the root of the sigillaria, which has a curious cross-shaped mark on its base,

[1] Such is the usual aspect of the plant. But as the stems have been, for the most part, greatly flattened by the pressure of the superincumbent rocks, the sharpness of the pattern has been much effaced. In some specimens described by Dr. Hooker, as having been found in an upright position, the external ornamentation presents an appearance somewhat different. What in the common specimens stand out as tubercules, are there seen to be deep circular cavities, in which the shrunk flagon-shaped bases of the rootlets are still observable. (See above, Fig. 13 *b*, which is taken from one of Dr. Hooker's plates. For a detailed description of the structure of stigmaria, see the paper above referred to in the *Geological Survey Memoirs*.) A very ornate species is mentioned by the late Hugh Miller, in which each tubercule formed the centre of a sculptured star, and the whole stem seemed covered over with flowers of the composite order. And what is, perhaps, still more curious, the stem was seen to end off in an obtuse point, tuberculed like the rest of the plant.—*Testimony of the Rocks*, p. 461.

the stems of stigmaria strike out horizontally, first as four great roots which subdivide as they proceed. Their subdivisions are dichotomous, each root splitting equally into two, and thus they want that intricate interlacing of rootlet which is so familiar to us. The whole disposition of these under-ground stems is singularly straight and regular, leading us to believe that they shot out freely through a soft muddy soil.

Some time ago I chanced to visit the remains of what had once been a royal residence, and still looked majestic even in decay. It gave a saddened pleasure to thread its winding stairs, and pass dreamily from chamber to hall, and chapel to closet; to stand in its gloomy kitchens, with their huge fire-places, whose blackened sides told of many a roaring fagot that had ruddied merry faces in days long gone by; to creep stealthily into the sombre dungeons, so dank, earthy, and cold, and then winding cautiously back, to emerge into the light of the summer sun. The silent quadrangle had its encircling walls pierced with many a window, some of which had once been richly carved; but their mullions were now sorely wasted, while others, with broken lintels and shattered walls above, seemed only waiting for another storm to hurl them among the roofless chambers below. In the centre of the courtyard stood a ruined fountain. It had been grotesquely ornamented with heads of lions and griffins, and was said to have once run red with wine. But it was silent enough now; the hand of time, and a still surer enemy, the hand of man, had done their worst upon it; its groined arches and foliaged buttresses were broken and gone, and now its shattered beauty stood in meet harmony with the desolation that reigned around. I employed myself for a while in looking over the fragments, marking now the head of some fierce hippogryph, anon the limbs of some mimic knight clad in armour of proof, and ere long I stumbled on a delicately sculptured *fleur-de-lis*, that might have surmounted the toilet-window of some fair one of old. Turning it over, I found its unhewn side exhibited a still more delicately sculptured stigmaria. The

incident was certainly simple enough, perhaps even trifling. And yet, occurring in a spot that seemed consecrated to reverie, it awoke a train of pleasant reflection. How wide the interval of time which was bridged across in that sculptured stone! Its one side carried the mind back but a few generations, the other hurried the fancy away over ages and cycles far into the dim shadows of a past eternity. The one told of a land of flowers, musical with the hum of the bee and the chantings of birds, and gladdened by the presence of man; the other told of a land luxuriant, indeed, in strange forms of vegetation—huge club-mosses, tall calamites, and waving ferns—yet buried in a silence that was only broken fitfully by the breeze as it shook the spiky catkins or the giant fronds of the forest. The *fleur-de-lis* recalled memories of France—the sunny land of France—which stood out so brightly in the dreams of our school-days; the stigmaria conjured up visions of a land that was never gazed on by human eye, but rolled its rich champaign during the long ages of the Carboniferous era, and sometimes rises up dimly in the dreams of our maturer years. Between these two epochs how many centuries, how many cycles must have slowly rolled away! The *fleur-de-lis* was carved but yesterday; the stigmaria flourished when the earth was young, and had seen scarcely a third part of its known history.

I have said that the stem of the stigmaria is called sigillaria. The name may be translated *signet-stem*,[1] and has reference to one of the distinguishing peculiarities of the plant. About twenty British species are enumerated, some of them very dissimilar, yet they all agree in having long fluted stems with parallel rows of prominent seal-like tubercules. The sigillaria differed so widely in its whole contour and ornamentation from every living plant, that it is impossible to convey an idea of its form

[1] The word *sigillaria* is really plural, and was used by the Romans to denote the little images which friends were wont to present to each other at the end of the Saturnalia. They answered pretty nearly to christmas-boxes and new year's gifts among ourselves. It is not uninteresting thus to find among the hard dry names of science, one that two thousand years ago was synonymous with all the kindliness of friendship.

by reference to existing vegetation. Some of the species, as *S. organum* (Fig. 14), had their trunks traversed longitudinally by broad ridges separated by narrow furrows. Along the summit of each ridge there ran a line of tubercules, set regularly at distances varying from a third or a quarter of an inch to close contact. One may sometimes see no unfair representation of the bark of this ancient tree, when looking at a newly ploughed field in spring-time, having each of its broad ridges dotted with a row of potato sacks. Other species, while exhibiting the same plan, differed not a little in the details. In some the tubercules are round, in others angular, and in a third set double or kidney-shaped. In some they are far apart, in others they are strung together like a chain of beads. Sometimes they exist as mere specks, while occasionally they broaden out so as to equal in width the ridge that supports them. One species (*S. reniformis*), instead of the broad ridge and narrow furrow, exhibits an arrangement exactly the reverse. It looks not unlike a cast of the species first described, save that its broad flat furrows support rows of much larger tubercules. The breast of a lady's chemisette, with a thick-set row of buttons down each plait, would be somewhat like this species of sigillaria, with this difference, however, that the buttons on the plant were of a form that does not appear as yet to have come into fashion among the fair sex. Yet they had no little elegance, and like

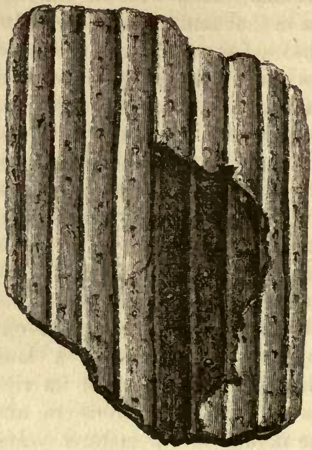


FIG. 14.—Sigillaria, with black carbonized bark partially removed.

many other objects in the geological storehouse, might be a useful model for our students of design. They were neither round nor quite oval, but rather of a kidney-shape, or like a double cherry.

There can be no doubt that these tubercules must once have supported leaflets. They are true leaf-scars, like those on the Scotch fir, and the lozenge-shaped knobs on the bark of lepidodendron. But of the form of these leaves we are still in ignorance, for no part of the plant, save the stem and roots, has yet been found. The sigillaria must have been a tree that could not long withstand maceration, for not only are its leaves gone, but, in many cases, the outer bark has partially or wholly decayed, leaving a scarcely distinguishable mass of carbonized matter.[1] When this outer rind is peeled off, the inner surface of the stem is seen to be ridged, furrowed, and tuberculed in the same way, but the markings are much less distinct than on the outside. The bark sometimes attains the thickness of an inch, and is always found as a layer of pure coal enveloping the stem where it stands erect, or lying as a flat cake without any central cylinder where the stem is prostrate. (See Fig. 14.)

Another remarkable feature in this carboniferous plant is that it appears to have had no branches along its stem. Trunks have been found four and five feet in diameter, and have been traced to a distance of fifty, sixty, and even seventy feet, without any marks of branches being detected. Brongniart examined the portion of one stem, which, at its thicker end, had been broken across, but still measured a foot in breadth. It ran for forty feet along the gallery of a mine, narrowing to a width of not more than six inches, when it divided into two, each branch

[1] Another proof of the looseness of the texture of this ancient vegetable may be gathered from the almost invariable truncation of even the largest erect stems; they are snapped across at the height of a few feet from their base. The famous "Torbanehill Mineral" contains many such fragmentary stems, often of considerable thickness. Their interior consists of the same material as the surrounding bed, and displays many dissevered plants that may have been washed into the decaying trunks. For the internal structure of sigillaria see Dr. Hooker's *Memoir*, and the authorities therein cited.

measuring about four inches across. The sigillaria stems, accordingly, must have shot up, slim and straight, to a height of sometimes seventy feet before they threw out a single branch. We know nothing of the coronal of these strangely-formed trees. From Brongniart's observations, it would seem that the upper part of the stem, like that of the lepidodendron, was dichotomous, that is, it branched out into two minor stems; but how these were disposed is unknown. We are wholly ignorant, too, of the foliage of these branches, though, from the general structure of the plant, as well as from the number of fern-fronds often found around the base of the stems, it has been conjectured that the sigillaria was cryptogamous, and, like the tree-ferns, supported a group of sweeping fronds. If so, it differed in many respects from every known member of the cryptogamic tribes.

Putting together, then, all that we know of the exterior of the sigillaria, we find that it was a tall slender tree, with, palm-like, a clump of foliaged branches above, its stem bristling thickly, in at least its upper part, with spiky leaves, and its roots equally hirsute, shooting out to a distance of sometimes forty feet through the soft muddy soil. Future researches may bring us better acquainted with this ancient organism. In the meanwhile, enough of it is known to mark it out as one of the most ornate forms of vegetation that the world has ever seen.

In addition to the above, the coal strata have yielded many other fragmentary remains, to which names have been given, but of which very little is known. It is pleasant, amid such a wide sea of doubt and uncertainty, to alight upon some well-known form of whose affinities there can be no question, since it still finds its representatives in living nature. Of such a kind are the coniferous stems occasionally met with in the sandstones of the coal-measures.

It is now many years since the operations of the quarryman in the carboniferous sandstones of Edinburgh and Newcastle disclosed the remains of huge gnarled trunks deeply imbedded

in the rock. The neighbourhood of the latter town yielded, in 1829,[1] the stem of a tree seventy-two feet long, without branches, but roughened with numerous knobs, indicative of the places whence branches had sprung. At Craigleith, near Edinburgh, a trunk thirty-six feet long, and three feet in diameter at the base, was disinterred in the year 1826. Since then, several others have been found in the same neighbourhood ; some of them sixty and even seventy feet in length, and from two to six in breadth. They were, for the most part, stripped of roots and branches, and lay at a greater or less angle among the white sandstone beds, which they cut across obliquely. It was unknown for some time to what division of the vegetable kingdom these trunks should be referred. Their irregular branched surface and undoubted bark indicated a higher kind of structure than that possessed by any of the other carboniferous plants ; but the conjecture remained unverified until an ingenious and beautiful method was discovered of investigating their internal organization. Two Edinburgh geologists, Mr. Nichol and Mr. Witham, succeeded in obtaining slices of the plants sufficiently transparent to be viewed under the microscope by transmitted light, and in this way their true structure was readily perceived. The method of preparing these objects was simply as follows :—A thin slice of the plant to be studied was cut by the lapidary, or detached by the hammer. One side having been ground down smooth, and polished, was cemented by Canada balsam to a piece of plate-glass, and the upper surface was then ground down and polished in like manner, so as to leave the slice no thicker than cartridge-paper.[2] When the preparation was then placed under a magnifying power, the minute cells and woody fibre of the plant could be detected as clearly as those of a recent tree. The Craigleith fossils were in this way recognised as belonging to

[1] Witham's *Foss. Veget.* p. 31.

[2] For a more detailed description of the process, see Witham's *Foss. Veget.* p. 45.

the great coniferous family, and to that ancient[1] division of it which is, at the present day, represented by the pine of Norfolk Island—"a noble araucarian, which rears its proud head from 160 to 200 feet over the soil, and exhibits a green and luxuriant breadth of foliage rare among the coniferæ."[2] Some of these plants have yielded faint traces of the annual rings shown so markedly in the cross section of our common forest-trees; whence it would appear, that even as far back as the times of the coal-measures, there were seasons of alternate heat and cold, though probably less defined than now.

These coniferous trees do not appear to occur among the erect stems of the coal-beds, at least they are very rare in such a position. Their more usual appearance is that of drifted, branchless trunks, imbedded along with other fragmentary plants in deep strata of sandstone. They probably grew on higher ground than the swamps which supported the sigillariæ and their allies, and might have been carried down by streams, freighted out to sea, and so deposited among the sediment that was gathering at the bottom.

The remains of cycadaceous plants have been described among the vegetation of the coal-measures; but only fragments have as yet been found. The modern *Cycadeæ* are low shrubs or trees, with thick stems of nearly uniform breadth, crowned with a dense clump of spreading fronds which resemble both those of the palms and the ferns. They are natives of the warmer regions of both hemispheres.

So long ago as the year 1835, Dr. Lindley figured a flower-like plant, to which he gave the name of *Antholites*, ranking it among the *Bromeliaceæ*, or pine-apple group. It was afterwards suspected by Dr. Hooker to belong rather to the coniferæ; and he supposed that the so-called flowerets

[1] The solitary lignite of the Lower Old Red Sandstone, seems to have been araucarian.—Miller's *Footprints of the Creator*, p. 203.

[2] *Footprints of the Creator*, p. 192.

might be really tufts of young unexpanded leaves. An examination of a more perfect specimen, however, has induced that distinguished botanist to alter his convictions and return to the original decision of Lindley, that the antholites are really flowers.[1] In Fig. 15, therefore, which represents one of these coal-measure fossils, the reader beholds the oldest flower that has yet been found; and surely it is of no little interest to know, that amid the rank, steaming forests of the Carboniferous era, with all their darkness and gloom, there were at least some flowers—flowers, too, that were allied to still living forms, and breathed out a rich aromatic fragrance.

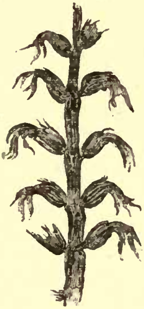


Fig. 15.—Antholites.

In fine, from all the genera and species of plants that have been detected in the strata of the coal-measures, it would appear that the flora of that ancient period was in a high degree *acrogenous*—that is to say, consisted in great measure of ferns, club-mosses, and other members of the great group of plants known as *acrogens*. This word literally means *top-growers*, and is applied to those plants which increase in height, but not in width, since they attain at first nearly their ultimate diameter. Such plants occupy a low position in the botanical scale. Mingled with the numerous genera of carboniferous ferns and club-mosses, we find the remains of a much higher grade of vegetation—that of the *gymnogens*, or plants that bear naked seeds—such as the firs and pines. There also seem to have been a few *endogenous* flowering plants. Viewing, then, this flora on the whole, it presents us with many striking resemblances to certain botanical regions of the present day. Many of the tropical

[1] See Dr. Hooker's remarks in the Supplement to the fifth edition of Lyell's *Manual*, p. 31.

islands abound in ferns, and contain very few flowering plants. But New Zealand affords perhaps the closest parallel. That island is in certain parts highly mountainous, its loftiest summits being covered with glaciers. The hills throughout large districts are bare, or covered with a scanty herbage, while in other localities they are densely clothed with forests of pine, beech, and other trees. These forests sweep on to the lower grounds, where they are replaced by a thick growth of fern and flax-plant intermingled with dragon-trees and graceful tree-ferns, while the more swampy regions support a rich profusion of reeds and rushes. Such a condition of things affords a close parallel to the probable vegetation of the Carboniferous period —an immense preponderance of ferns and arborescent acrogens, with an intermixture of large coniferous trees. From the general scantiness of a flora where ferns predominate, it has been argued that the swamps of the coal-measures nourished a luxuriant repetition of comparatively few species; and this hypothesis also receives confirmation from the vegetation of New Zealand. Another deduction founded on the resemblance of the ancient to the modern flora, refers to the conditions of heat and moisture. It has been inferred that the climate of the coal period was equable and humid, like that of New Zealand—a supposition much more natural and simple than that, once so much in vogue, of a heated atmosphere densely charged with carbonic acid gas. That the air of the Carboniferous period differed in no material respect from the air of the present day, seems at last proved by the remains of air-breathing animals having been found among the coal-beds; and there seems no reason why the higher mountain-tops of the same epoch may not have been clothed with glaciers as those of New Zealand are. As yet we have no evidence of the fact, but it is by no means beyond the possibility of proof.[1]

[1] See Professor Ramsay's suggestive Memoir on Permian Breccias in *Quarterly Journal of the Geological Society*, vol. xi. p. 185.

CHAPTER V.

Scenery of the carboniferous forests—Contrast in the appearance of coal districts at the present day—Abundance of animal life in the Carboniferous era—Advantages of palæontology over fossil-botany — Carboniferous fauna — Actiniæ — Cup-corals — Architecture of the present day might be improved by study of the architecture of the Carboniferous period—Mode of propagation of corals—A forenoon on the beach—Various stages in the decomposition of shells—Sea-mat—Bryozoa—Fenestella—Retepora—Stone-lilies—Popular superstitions—Structure of the stone-lilies—Aspect of the sea-bottom on which the stone-lilies flourished—Sea-urchins—Crustacea, their high antiquity—Cyprides—Architecture of the crustacea and mollusca contrasted—King-crabs.

THE forms of vegetation that flourished during the Carboniferous era seem to have been in large measure marshy plants, luxuriating on low muddy delta-lands, like the cypress-swamps of the Mississippi, or the Sunderbunds of the Ganges. We can picture but faintly the general scenery of these old forests from the broken and carbonized remains that have come down to us. But though perhaps somewhat monotonous on the whole, it must have been eminently beautiful in detail. The sigillariæ raised their sculptured stems and lofty waving wreaths of fronds high over the more swampy grounds, while a thick underwood of ferns and star-leaved asterophyllites clustered amid the shade below. The lepidodendra shot forth their spiky branches from the margin of green islets, and dropped their catkins into the sluggish water that stole on among the dimpled shadows underneath. Tree-ferns spread out their broad pendant fronds, and wrapt the ground below in an almost twilight gloom, darker and deeper far than that

"Hospitable roof
Of branching elms star-proof,"

which rose so often in the visions of Milton; or that "graceful arch" so exquisitely sung by Cowper, beneath which

> "The chequered earth seems restless as a flood
> Brushed by the wind. So sportive is the light
> Shot through the boughs, it dances as they dance,
> Shadow and sunshine intermingling quick,
> And darkening and enlightening, as the leaves
> Play wanton, every moment, every spot."

Thickets of tall reeds rose out of the water, with stems massive as those of our forest-trees, encircled at regular distances by wreaths of pointed leaflets, and bearing on their summits club-like catkins. Far away, the distant hills lay shaggy with pine-woods, and nursed in their solitudes the springs and rivulets that worked a devious course through forest, and glen, and valley, until, united into one broad river, they crept through the rich foliage of the delta and finally passed away out to sea, bearing with them a varied burden of drift-wood, pine-trees from the hills, and stray leaves and cones from the lower grounds.

How different such a scene from that now presented by the very same areas of country! These old delta lands are now our coal-fields, and have exchanged the deep stillness of primeval nature for the din and turmoil of modern mining districts. In these ancient times, not only was man uncreated, but the earth as yet lacked all the higher types of vertebrated being. None of the animals that we see around us existed then; there were no sheep, nor oxen, horses, deer, nor dogs. Neither were the quadrupeds of other lands represented; the forests nourished no lions or tigers, no wolves or bears, no opossums or kangaroos. In truth, the land must have been a very silent one, for we know as yet of no animated existence that could break the stillness, save perchance some chirping grasshopper, or droning beetle, or quivering dragon-fly. No bee hummed along on errands of industry; it is doubtful, indeed, whether honey-yielding

flowers formed part of the carboniferous flora; no lark carolled blithely in the sky, nor rook croaked among the woods. All was still; and one might, perhaps, have stood on some of those tree-crested islets, and heard no sound but the rippling of the water along the reedy and sedgy banks, and the rustling of the gloomy branches overhead.

To one who muses on these bygone ages it is no unimpressive situation to stand in the midst of a large coal district and mark its smoking chimneys, clanking engines, and screaming locomotives, its squalid villages and still more squalid inhabitants, and its mingled air of commercial activity, physical wretchedness, and moral degradation. It is from such a point of view that we receive the most forcible illustration of those great changes whereof every country has been the scene, and which are so tersely expressed by one who has gazed on the revelations of geology with the eye of a true poet—

> "There rolls the deep where grew the tree.
> O earth, what changes hast thou seen!
> There where the long street roars, hath been
> The stillness of the central sea."

But the lifelessness of the carboniferous forests was amply compensated by the activity that reigned in river, lagoon, and sea. Coral groves gleamed white beneath the waves, fishes of many a shape disported in stream and lake, and the bulkier forms, armed in massive plates of bone, ascended the rivers or haunted the deeper recesses of the open sea. In some beds of rock the remains of these various animals lie crowded together like drifted tangle on the sea-shore, and the whole reminds us of a vast cemetery or charnel-house. The bones lie at all angles, many of them broken and disjointed as though the owner had died at a distance, and his remains, sadly mutilated on the way, had been borne to their last resting-place by the shifting currents; others lie all in place, covered with their armature of scales, as though the creature, conscious of approach-

ing dissolution, had sought out a sheltered nook and there lain down and died. It is not uninteresting or uninstructive to trace out in an old quarry stratum above stratum, each with its groups of once living things. I know of few employments more pleasant than to sit there, amid the calm stillness of a summer evening, when the shadows are beginning to steal along the valleys and creep up the hill-sides, and in that dim fading light to try in fancy to clothe these dry bones with life, to picture the time when they lived and moved in the glassy depths of lakes and seas, or amid the solitudes of jungles and forests, and so to spend a pleasant hour in reverie, till roused at last by the vesper song of the lark, or the low moanings of the night wind as it sighs mournfully through the woods.

The study of fossil animals embraces a much greater range of subject than that of fossil plants. The *fauna* of any particular geological formation, that is to say, its embedded animal remains, for the most part vastly exceeds in number its *flora*, or vegetable remains, and is likewise usually better preserved. About the nature and affinities of several tribes of fossil plants there hangs an amount of uncertainty which renders them a dubious guide to the climatal and other conditions of the period and locality in which they lived. Generic distinctions among living plants often rest on the character of those parts which are the most perishable, such as flowers and seed-vessels. These delicate structures we, of course, can hardly look to find preserved in the rocks, and we have in place of them only detached leaflets, twigs, branches, and stems, often sorely mutilated in outward form, and presenting no trace of internal organization. But the tribes of the animal kingdom have, for the most part, harder frameworks. The minute infusoria, which by their accumulated remains help to choke up the delta of the Nile, and swarm by millions in every ocean of the globe, have their silicious or calcareous shells so minute that Ehrenberg has estimated a cubic inch of tripoli to contain forty-one thousand millions of them. The polypi

have their internal calcareous skeletons, which abound in all the older limestones, and form the coral reefs of the present day. The mollusca, too, though, as their name imports, they have perishable bodies, are yet, in most cases, furnished with hard calcareous shells, that indicate by their various modifications of form and structure, the character of the animal that lived within them. They are found in all the formations from the earliest upwards, and as they vastly exceed in numbers all the other classes with which the geologist has to deal, they form the larger part of that basis of evidence from which he interprets the past history of organized existence. Hugh Miller loved to talk of them as the "shell alphabet," out of which the language of palæontological history should be compiled. The vertebrata, too, all have their hard skeletons, easily capable of preservation, whether it be in the form of the massive exo-skeleton of bone that characterized the older ganoidal fishes, or the compact endo-skeleton of the reptiles and mammals. A greater amount of attention is, therefore, due to the study of fossil animals, since they thus not only far exceed fossil plants in number, but possess a higher value as evidence of ancient physical conditions.

The *fauna* of the Carboniferous system is a very numerous one, exhibiting specimens of almost every class of animal life, from the tiny *foraminifer* up to the massive bone-covered sauroidal fish, and even to occasional traces of true reptilian remains. By far the larger number are peculiar to the sea, such as the molluscan tribes and corals; others are undoubtedly terrestrial organisms, such as the wings and wing-sheaths of several kinds of insects; while some appear to be peculiar to fresh or brackish water, such as shells allied to our *unio* or river-mussel, and minute crustaceous animals known as *cyprides*, of which we have still representatives in our ponds and ditches. It is plain, then, that if we rightly ascertain the class or family to which one of these fossils belonged, we shall obtain a clue

to the history of the physical geography, during Carboniferous times, of the district in which the fossil occurs. A bed of unios will tell us of old rivers and lakes that spread out their blue waters where now, perchance, there lie waving fields of corn. A bed of corals and stone-lilies will lay before us the bottom of an ancient ocean that rolled its restless waves where to-day, perhaps, the quarryman plies his task amid the gloom of dark pine-woods. In short, these organic remains are to the history of the earth what ancient monuments are to the history of man. They enable us to trace out the varied changes of our planet and its inhabitants down to the human era, just as the wooden canoe, the flint arrow-head, the stone coffin, the bronze sword, the iron cuirass, the ruined abbey, and the feudal castle, teach us the successive stages of progress in the history of our own country.

Whoever has spent a few days on some rocky coast, must have noticed adhering to half-tide stones nunerous solitary *actiniæ*. Arrayed in all the colours of the rainbow—purple, green, and gold—these little creatures hang out their tentacles like so many flowers, and have hence received the popular name of sea-anemones. Their internal structure is no less beautiful. They resemble so many large plump gooseberries, and consist of a little sack suspended within a larger one. The outer sack is fringed along its upper edges with one or more rows of slim hollow tentacles, which diverge outwards like the petals of the daisy, and can be contracted at pleasure so as somewhat to resemble the daisy when folded up at sunset. The inner sack, which forms the stomach of the animal, has a short opening or gullet, at the upper part of which is the mouth lying in the centre of the cavity surrounded by the fringes of tentacles. The inner sack is connected with the outer by means of thin membranes, like so many partition-walls, which radiate inwards like spokes towards the axle of a wheel. The space between each of these membranes, or lamellæ, forms an independent chamber, but it has a com-

munication with those on either side by a window in each wall, and further opens upwards into the hollow tentacles, which, with minute orifices at their outer points, may be compared to chimneys. These chambers form the breathing apparatus of the little creature. Sea-water passes down through the tentacle into the hollow chamber below, whence, by the constant action of minute hairlike cilia that line the walls like tapestry, it is driven through the window into the next chamber, thence into the next, and so on, passing gradually through the tentacles back to the sea.

The actiniæ are of a soft perishable substance, but many of the other *Anthozoa*, or flower-like animals, have hard calcareous skeletons. Of such a kind are the polypi that in the Pacific Ocean have raised those stupendous reefs and islands of coral. It does not appear that, during the Carboniferous period, there existed any reef-building zoophytes, but some of the most abundant forms of life belonged to a kindred tribe, and are known by the name of *Cyathophyllidæ*, or cup-corals.

As the name imports, the typical genus has a general cup-shaped form, but this is liable to many aberrations in the cognate genera. The younger specimens of one species (*Cyathopsis fungites*) have a curved outline somewhat like the bowl of a tobacco-pipe, whence the quarrymen know them as *pipe-heads.* The older individuals are generally more or less wrinkled and twisted, sometimes reaching a length of eight or nine inches, and have been named by the workmen *rams'-horns.*

The annexed figure (Fig. 16) shows their general appearance and structure. The lower end was fixed to the rock like the flat sucker-like disc of the actinia. Around the outer margin there diverged one or more rows of slim tentacles, hollow, soft, and retractile, like those of the actinia. From the margin to the centre there radiated more than a hundred lamellæ, but these differed from the corresponding membranes of the modern animal, inasmuch as they were strengthened internally by a

skeleton of hard carbonate of lime; and to this difference we owe their preservation. They stand out in high relief upon weathered specimens, showing the long, narrow chambers that ran between them. Their walls were once doubtless hung with countless vibratile cilia, and perhaps pierced each with its window, through which the currents of water passed in their ceaseless progress to and from the sea. At the centre lay the mouth, communicating by a short gullet with the stomach, which occupied the central portion of the animal, and from the outer walls of which the lamellæ diverged like so many buttresses. In its youngest stages, the animal occupied the whole length of the cup, but, as it increased in size, it gradually retreated from the narrow end, which was then divided off by a thin calcareous membrane. At each successive stage of its growth, a new membrane was added, each further and further from the lower end, so that eventually the creature left below it a series of empty chambers all firmly built up. Thus, in a specimen six or eight inches long, there would in reality only be a small part tenanted—in fact merely the upper floor—all the lower storeys remaining silent and uninhabited. The house of this old-world architect differed widely in one respect from human dwellings. Man begins his basement story of the same dimen-

FIG. 16.—Cyathopsis (clisiophyllum ?) fungites.

sions as those that are to succeed it, or, if any difference is made at all, the upper floors are built each less than the one below it, so that the whole structure tapers upward to a point, as in the Pyramids. But the cyathopsis reversed this latter process; it inverted the cone, commencing the smallest chamber at the bottom, and placing the widest at the top. Indeed, one is sometimes puzzled to conjecture how so bulky a building could be securely poised on so narrow a basis, and it is certainly difficult to see how the creature could move about with such a ponderous load to drag along. The snail carries his house on his back, yet it is a slim structure at the best; but the cup-coral must not merely have carried his house, but some dozen or two of old ones strung one after another to his tail. Perhaps, though free to move about and try change of residence in its youthful days, the creature gradually settled down in life, and took up its permanent abode in some favourite retreat, the more especially as in process of time it became what we should call a very respectable householder.

Allied to the cyathopsis is another and still more beautiful coral, described so long ago as the latter part of the seventeenth century by the Welsh antiquary and naturalist, Lhwyd, under the name of *Lithostrotion.* Although many perfect specimens of it have been found, and it is usually as well preserved as any of its congeners, men of science have been sadly at a loss what to call it. Four or five synonyms may be found applied to it in different works on palæontology. There seems now, however, a tendency to return to the name that old Lhwyd gave it two centuries ago; the family to which it belongs, and of which it is the type, has accordingly been termed the *Lithostrotionidæ*, and the species in question *Lithostrotion striatum* (Fig. 17). It differed from the cyathopsis in several respects, but chiefly in this, that it lived in little congregated groups or colonies, whereas the cyathopsis, like our own actinia, dwelt alone.

Each of these colonies was formed of a cluster of hexagonal, or rather polygonal pillars, fitting closely into each other, like

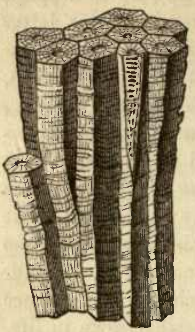


FIG. 17.—Lithostrotion striatum.

the basaltic columns of Fingal's Cave, and springing from a common base at the sea bottom.[1] Each pillar constituted the abode of a single animal, and resembled generally the stalk of the cyathopsis. It had the same minute diverging partitions running from the outer walls towards the centre, and the same thin diaphragms, which, stretching horizontally across the interior of the column at short intervals, marked the successive stages of the animal's growth. Within these partitions, which vary from forty to eighty in number, there runs an inner circular tube with thin lamellæ and diaphragms. The exterior of the columns is ribbed longitudinally by a set of long fine striæ, which give somewhat the appearance of the fluting on a Corinthian pillar. The columns, moreover, are not straight, but have an irregular, wrinkled outline, so that, by a slant light, they look like some old pillar formed of many layers of stone, the joints of which have wasted away, producing an undulating profile in place of the original even one. But in these ancient coral columns there is no blunted outline, no worn hollow; the sculpturing stands out as sharp and fresh, and the wavy curves as clearly defined, as though the creature had died but yesterday. They resemble no order of human architecture, save faintly, perhaps, some of the wavy outlines of the Arabesque.

Despite all the improvements and inventions of modern times, classic architecture has made no progress since the days of Pericles. All that we do now is but to reproduce what the

[1] Sir Roderick Murchison figures in his *Siluria*, p. 282, a gigantic specimen, which measured two feet four inches in width.

Greeks created 2000 years ago, and he is reckoned the best architect who furnishes the best imitation. Our architects might find some useful hints, however, by studying the lowlier orders of nature. They would see there patterns of beauty far more delicate than the Grecian capital, and more light and airy than the Gothic shaft. And whether or not they could found a new order of architecture, they could not fail to discover many modifications and improvements upon some of the old. They could not readily light upon a more graceful form than that of the lithostrotion, would they but picture it as it grew at the bottom of the old carboniferous sea. A group of hexagonal pillars, firmly compacted together like those of the Giant's Causeway, or Fingal's Cave, rose from a white calcareous pediment, as columns from the marble steps of an Athenian temple. Each side of the pillar had a wavy undulating surface, delicately fluted by long slender striæ, the whole being so arranged that the convexities of one surface fitted into the sinuosities of the adhering one. Each pillar was crowned above by a capital, consisting of the soft vibratile tentacles of the animal, that hung over like so many acanthus leaves. Of the form of these tentacles, their design and grouping, we know nothing save what may be gathered from the analogy of living corals. There can be little doubt, however, that, like the flower-shaped buds of the existing reef-building polyps, they must have been eminently beautiful, and in strict keeping with the graceful column which they crowned.

Another kindred form was that known as the *lithodendron*. It, too, grew in colonies, and seems to have closely resembled the last, save that the pillars, in place of being six-sided, were round. I have seen a bed of these corals several yards in extent, and seven or eight inches deep, where the individuals were closely crowded together, so as to resemble a series of tobacco-pipe stems, or slim pencils set on end. The tubes, however, were not all quite straight; many being more or less

curved, and sometimes crossing their neighbours obliquely. The internal arrangement was on the same plan as in the two previous corals. The same numerous partitions ran from the exterior wall towards the central tube, the same thick-set diaphragms crossed the entire breadth of the column, imparting the same minute honey-combed appearance to a cross section. The exterior of the column (in *L. fasciculatum*) was likewise traversed by the same longitudinal striæ.

Both these corals seem to have been *fissiparous*, that is to say, they propagated by splitting into two parts, each of which formed the base of a new column with a new animal. The evidence for this statement rests on the fact, that many of the tubes are seen to bifurcate in their course, so that two new tubes are produced equal in size and completeness to the old one from which they proceed. Another mode of generation which, in at least its earlier stages, would produce a somewhat similar appearance is called *gemmation*, and consists in the protrusion of a bud or gemmule from the side of the animal, which shortly develops into a new and perfect individual. It is probable, however, that the ordinary mode of propagation among these old corals was the usual one by impregnated ova. These ova, like those of our sea-anemones, were probably generated within the partitions, between the central stomach and the outer wall, whence they passed down into the stomach, and were ejected by the mouth of the parent as little gemmules, furnished with the power of locomotion by means of vibratile cilia. Some of the *Medusa* family possess this three-fold mode of propagation ; but, in all, the last-mentioned is the most usual.

Has the reader ever stretched himself along the shore, while, perhaps, a July sun blazed overhead, and a fitful breeze came over the sea, just strong enough to chase ashore an endless series of rippling wavelets, and breathe over his temples a delicious and refreshing coolness ? Thus placed, and gazing dreamily now, perchance, at the distant sails like white specks

along the boundary line of sea and sky ; now at the gulls wheeling in broad circles through the air, and shooting swift as arrows down into the blue water, he must often have turned to look for a little at the sand which, heaped up in little mounds around him, formed a couch well-nigh as soft as the finest down. Many a varied fragment entered into the composition of that sand. Mingled among the minuter quartzy particles lay scores of shells, some with the colour not yet faded, and the valves still together—the delicate tellina, with its polished surface, and its flush of pink ; the cardium with its strong white plaited sides, and the turritella with its circling spire ; some were worn down and sorely effaced, others broken into fragments by the ceaseless grinding of the waves. It was pleasant labour in such a sultry noon to pick out the shells of one species in all stages of decay. The *Trochus lineatus*, or Silver Willie, as young ramblers by the sea-shore love to call it, showed well the process of destruction. The perfect shell, cast ashore, perhaps, by the last storm, and still uninjured by the tides, displayed its russet epidermis, or outer skin, covered with fine brown zig-zag lines, running across the whorls from the creature's wide pearl-lined mouth to the apex. A second shell exhibited a surface that had begun to suffer ; the point had been divested of its thin outer skin, and laid bare the silvery coating of pearl below. A third had undergone a still longer period of abrasion, for the whole of the epidermis was gone, and the surface gleamed with a pearly iridescence. In yet a fourth, this bright exterior had been in large measure worn away, and the blunted, rounded shell displayed the dull white calcareous substance of which it was mainly built up. But there were other objects of interest in the sand : bits of tangle, crusted over with a fine net-work of gauze, and fragments of thin leaf-like membrane, consisting of a similar slender net-work known popularly as the *sea-mat*, occasionally turned up among the pebbles and shells. No one who met with these

organisms for the first time could fail to be struck with the extreme delicacy of finish, if one may so speak, that characterizes them. And yet he might be puzzled to know what to make of them. The leaf-like membrane, at a first glance, looks not unlike some of the flat-leaved algæ, and such the observer might readily take them to be. Such, too, they were long regarded by naturalists; but a more careful examination of them showed that the so-called plants really belonged to the animal kingdom, and that the supposed leaves were, in truth, the organic dwelling-places of minute zoophytes, of which many hundreds lay grouped together on every square inch. For many years these little creatures were called "celliferous corallines," and classed among the polypi, that great tribe which has its representatives in every ocean, from the coral reefs of the Pacific to the little bell-shaped *hydra* amid the tangle of our own seas. But the microscope—that lamp which lights us into the inner recesses of nature—revealed at last their true character. Fixed to one spot, living in communities, and exceedingly minute, in short, with many of the outward features of the true corallines, they were yet found to possess a structure so complex and highly organized, as to entitle them to rank among the higher tribes of the invertebrate animals, and they are now accordingly pretty generally subjoined to the mollusca, under the name of *Bryozoa*.

Each bryozoon consists externally of a single horny or calcareous cell, sometimes furnished with a valve-like lid that folds down when the animal withdraws itself. When danger is past, and the creature begins again to emerge, the upper parts, which were drawn in like the inverted finger of a glove, are pushed out until a series of tentacles, covered with minute hair-like bodies, called cilia, are expanded. The vibratile motion of these cilia causes a constant current in the direction of the mouth, which lies in the centre of the hollow whence the tentacles spring; animalcules are in this way brought in rapid suc-

cession within reach of the mouth, and form a never-failing source of nourishment. The interior is greatly more complex than that of the *polypi.* The stomach is connected above with a cavity like the gizzard of a bird, furnished with pointed sides, which serve to triturate the food before it passes into the stomach. There is also a distinct intestine. The muscular action for the expansion and retraction of the animal is highly developed, and the generative system is a greatly more complex one than that of the polyps already referred to. In short, however closely they might be thought to resemble the corals in outward form, their internal structure undoubtedly links them with a much higher type of organization, and justifies the naturalist in subjoining them as a sub-order to the mollusca.

The cells are grouped at short intervals along a horny or calcareous substance, that sometimes encrusts seaweed, or spreads out as a flat leaf-like membrane, or rises into cup-shaped or dendritic forms. A series of cells constituting a separate and independent colony, is termed a polypidom. The cells are further connected together by an external jelly-like integument, in which they are sunk, and which serves to secrete the calcareous particles from the sea.

It is interesting to know that creatures so minute and yet so complexly organized, existed abundantly in the seas of the Carboniferous period. No less than fifty-four species are enumerated as having been obtained from the carboniferous strata of the British Islands, and scarcely a year passes without one or two new species being added to the list. The most frequent belong to the genus *Fenestella*, or little window, a name indicative of the reticulated grouping of the branches like the wooden framework of a window. Each of these branches, or interstices, as they are called, was more or less straight, being connected with that on either side by a row of transverse bars, just as the central mullion of an abbey window is connected with the flanking ones by means of cross-bars of stone. Not unfrequently some of the branches subdivide into two, as we saw to be the

case among the cup-corals. Fig. 18 illustrates the relative disposition of these branches. In *a*, the natural size of the

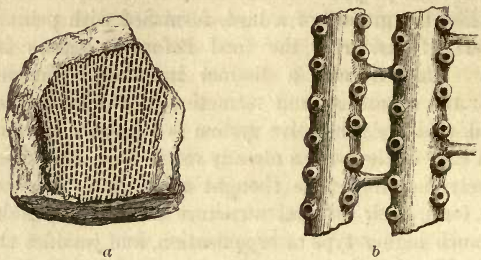


Fig. 18.—*a*, Fenestella oculata (M'Coy), nat. size; *b*, magnified portion of the same.

fossil is given; *b* is a portion of the same magnified, to show the form and arrangement of the ribs and cross-bars. Each rib is seen to have two sides separated by a rounded ridge. Along each side there runs a row of circular hollows or cells, every one of which once formed the abode of a distinct bryozoon. The back or inner surface of the branch, was ribbed and granulated irregularly, without any cells. The connecting bars or dissepiments have no cells, and served merely to bind the interstices together into one firm organically-united polypidom. Such fragments as that here figured are the most usual traces to be found of these animals among the carboniferous rocks. But perfect specimens are sometimes met with which show how delicate and graceful a structure the polypidom of some of the fenestellæ must have been. All these bars sprung from a common point as their basis, and rose up in the form of a cup. It was, in short, a cup of network, hung with waving tentacles and quivering cilia. I have seen some dissections of flowers in which all the softer tissue had been removed, so as to present only the harder veinings of the leaves with their thousand ramifications bleached to a delicate whiteness. Out of these

skeleton-leaves there were formed groups of lilies, crocuses, geraniums, and roses, like patterns of the finest gauze. Some of the larger-stemmed leaves that had been artistically moulded into a tulip form, seemed not inaptly to represent the general contour of the skeleton of the old carboniferous fenestella.

An allied form is called the *Retepora.* It differed from the previous organism in having the ribs not straight, but irregularly anastomosing, that is, running into and coalescing with each other, so as to form a close network with oval interspaces, like a piece of very minute wire-fence. Each of these wavy ribs was completely covered over on one side with oval pores or cells, which, as in the fenestella, formed the abode of the living animals. The differences in organization between the animal of fenestella and that of retepora can, of course, only be matter of speculation. The general structure in both must, however, have been pretty much alike. The former genus is now no longer extant, but the latter, which was ushered into the world during the era of the Old Red Standstone, still lives in the deeper recesses of the ocean, and manifests in its structure and habits the leading characteristics of bryozoan life.

What rambler among old lime-quarries is not familiar with the stone-lily, so abundant an organism in most of the Palæozoic and many of the Secondary limestones? In some beds of the carboniferous limestone its abundance is almost incredible. I have seen a weathered cliff in which its remains stood out in bold relief, crowded together, to use an expression of Dr. Buckland's, "as thickly as straws in a corn-rick." The joints of this animal, known now as *entrochi* or wheel-stones, forced themselves on the notice of men during even the middle ages, and an explanation was soon found for their existence. From their occurring largely about the coast at Holy Island, they were set down as the workmanship of Saint Cuthbert.

"On a rock by Lindisfarne,
St. Cuthbert sits and toils to frame
The sea-born beads which bear his name."

The aged saint was represented as employing his nights in this highly intellectual task, sitting on a lone rock out in the sea, and using an adjacent one as his anvil.

> "Such tales had Whitby's fishers told,
> And said they might his shape behold,
> And hear his anvil sound,
> A deaden'd clang,—a huge dim form
> Seen but, and heard, when gathering storm
> And night were closing round."

But these wheel-stones were not the only geological curiosities to which this simple mode of explanation was applied. In the same storied neighbourhood there occur in considerable numbers the round whorled shells of the genus *Ammonites*. These were gravely set down as petrified snakes wanting the head, and their petrifaction and decapitation were alike reverently ascribed to the power of the sainted abbess of Whitby.

> "They told
> How of a thousand snakes each one
> Was changed into a coil of stone
> When holy Hilda prayed."

The stone-lily belonged to that large class of animals ranked together as *Echinodermata*, a name taken from one of the leading subdivisions of the group—the *Echini* or sea-urchins. It seems to have been one of the earliest forms of life upon our planet, its disjointed stalks occurring largely in some of the oldest Silurian limestones. In the Secondary ages it began gradually to wane, until at the present day its numerous genera appear to be represented by but the *comatula* and the *pentacrinite*, two tiny forms that float their jointed arms in the profounder depths of the sea.

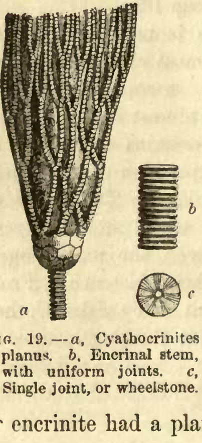


FIG. 19.—*a*, Cyathocrinites planus. *b*, Encrinal stem, with uniform joints. *c*, Single joint, or wheelstone.

As its name imports, the stone-lily or encrinite had a plant-like form. It consisted of a long stalk

fixed by the lower end to the sea-bottom, and supporting above a lily-shaped cup, in which were placed the mouth and stomach (Fig. 19 *a*). The stalk consisted of circular plates (some of them not so thick as a sixpence), having their flat sides covered with a set of minute ribs radiating from the centre, and so arranged that the prominent lines of one joint fitted into corresponding depressed lines of the adhering ones. The centre of each joint was pierced by a small aperture, like the axle of a wheel, which, when the stem was entire, formed part of the long tube or canal that traversed the centre of the stem, and served to convey aliment to the remotest part of the animal. Detached joints have thus a wheel-like appearance (Fig 19 *c*), and hence their common name of wheel-stones. In many species they were not all of the same diameter, but alternately larger and smaller, as if the stem had been made up of a tall pile of sixpences and threepenny pieces in alternate succession. This variation gives a remarkably elegant contour to the stalk. The flower-shaped cup consisted of a cavity formed of geometric calcareous plates, and fringed along its upper margin with thick calcareous arms, five or ten in number, that subdivided into still more slender branches, which were fringed along their inner side with minute *cirri* or feelers. All these subdivisions, however fine, were made up of calcareous joints like the stalk, so that every stone-lily consisted of many thousand pieces, each perfect in its organization and delicate in its sculpturing. One species peculiar to the Liassic formation (*Extracrinus Briareus*) has been calculated to contain one hundred and fifty thousand joints !

The effect of this minute subdivision was to impart the most perfect flexibility to even the smallest pinnule. The flower could instantly collapse, and thus the animals on which the encrinite preyed were seized and hurried to the central mouth. The lower part of the cup, or *pelvis*, as it is called, contained the stomach and other viscera, and communicated with the

most distant part of the body by the central alimentary canal.

But while this continued the general type on which the encrinites were constructed, it received many minor modifications. These were effected chiefly on the form and arrangement of the cup-shaped body and its appendages, and form now the basis of our classification into genera and species. Thus, in the genus known as *Platycrinus*, the lower part of the cup consists of two rows of large hexagonal or polygonal plates fitting closely into each other, while the upper part rises into a dome-like elevation formed of smaller polygonal plates, which have often a mammillated exterior. The arms sprang from the widest part of the body where the large pieces of the lower cup were succeeded by the small pieces of the upper. In an Irish species (*P. triacontadactylus*), the arms subdivided into thirty branches, each fringed with minuter pinnules and folding round the central elevated spire, as the petals of a crocus close round its central pistil. In another encrinite (*Poteriocrinites conicus*), the cup was shaped like an inverted cone, the point being affixed to the summit of the stalk, and the broad part throwing out from its edges the lateral arms. The *Woodocrinus macrodactylus* had such gigantic arms as wellnigh to conceal the position of the cup, which relatively was very small in size. They sprang from near the base of the cup, five in number, but soon subdivided each into two, the ten arms thus produced being closely fringed with the usual jointed calcareous pinnules.

The size and arrangement of the joints of the stalk also differed in different genera. The Woodocrinus and many others had them alternately broad and narrow, like a string of buttons of unequal sizes ; others had all the joints of the same relative diameter (Fig. 19 *b*), so that the stalk tapered by a uniform line from base to point. I may add, that on some specimens of both these kinds of stems, we can notice small, solitary *areolæ*, or scars, which may mark the points of attachment of cirri, or little

tentacles, like those on the stem of the existing Pentacrinite. But though each of these varieties of stem is peculiar to a certain number of genera, there is often so little distinction among the detached fragments, that it becomes difficult, indeed impossible, to assign each to its appropriate individual. We may say, that certain encrinal stalks could not have belonged to a poteriocrinus, and others could never have fitted on to the cup of an actinocrinus ; but we cannot often say positively to what species they actually would have fitted. There can, however, be no doubt about their being encrinites, and so we have in them a safe and evident test for the origin of the rock in which their remains occur. But to this I shall afterwards revert.

In the meantime, I would have the reader to fix the stone-lily in his memory as peculiarly and emphatically a marine animal, dwelling probably in the deeper and stiller recesses of the ocean, like the Pentacrinite of existing times. Let him try to remember it, not in the broken and sorely mutilated state in which we find it among the blocks of our lime-quarries, but as it must have lived at the bottom of the carboniferous seas. The oozy floor of these old waters lay thickly covered with many a graceful production of the deep, submarine gardens of

> "Violet, asphodel, ivy, and vine-leaves, roses and lilies,
> Coral and sea-fan, and tangle, the blooms and the palms of the ocean."

Amid this rich assemblage of animated forms, the stone-lilies must have occupied a conspicuous place. Grouped in thick-set though diminutive forests, these little creatures raised their waving stems, and spread out their tremulous arms, like beds of tulips swaying in the evening air. Their flower-like cups, so delicately fringed, must have presented a scene of ceaseless activity as they opened and closed, coiling up while the animal seized its prey, or on the approach of danger, and relaxing again when the food had been secured, or when the symptoms of a coming enemy had passed away. Only from this animated

action would one have been apt to conjecture these organisms to be other than vegetable. They lived, too, not in detached patches, like the tulip-beds of the florist, but, to judge from the abundance of their remains, must have covered acre after acre, and square mile after square mile, with a dense growth of living, quivering flowers. As one individual died out, another took its place, the decaying stems and flowers meanwhile falling to pieces among the limy sediment that lay thickly athwart the sea-bottom, and contributing, by their decay and entombment, to build up those enormous masses of rock, known as the mountain-limestone, which stretch through Yorkshire and the central counties into Wales.

In addition to the stone-lilies, the carboniferous rocks contain the remains of several other kinds of *Echinodermata*. Some of them find their nearest modern analogues among the sea-urchins so common on our shores; but I pass on to notice another very interesting class of fossils known by the name of *Crustacea*, and still abundantly represented, the crab and lobster being familiar examples.

The Crustacea, so called from the hard crust or shell which envelops them, form, with all their orders and genera, a very numerous family. They are of interest to us as containing among their number some of the oldest forms of life. Away down in the lower Silurian rocks, among the most ancient fossiliferous strata, we find the crustacean with its armour of plates and its prominent sessile eyes set round with lenses, still visible on the stone. Thus, on the first page of the stony records of our planet's history are these primeval organisms engraved. In some localities, where oxide of iron is largely present, they are coated with a bright yellow efflorescence, and stand out from the dull grey stone like figures embossed in gold.[1]

[1] Such is the aspect of the organisms in some of the Silurian sandstones near Girvan. I have seen the same bright tint on a set of fossils from the Llandeilo flags of Wales, and from the slates of Desertcreat, Ireland, and have disinterred similarly gilded shells from

On all the subsequent leaves of this ancient chronicle, we can detect the remains of crustacean life, and many tribes still swarm in our seas and lakes. It is interesting, however, as marking the onward progress of creation, to notice that, though this great family has continued to live during all the successive geological ages, its members have ever been changing, the older types waning and dying out, while newer genera rose to supply for a time their place, and then passed away before the advance of other and yet later forms. The trilobites that meet us on the very verge of creation, swarmed by millions in the seas of the Silurian ages, diminished gradually during the era of the Old Red Sandstone, and seem to have died out altogether in the times of the Coal. In no ocean of the present day is a trace of any of their many genera to be seen. The *decapods*, of which our common crab is a typical form, began to be after the trilobites had died out. In all the subsequent eras they gradually increased in numbers, and at the present day they form the most abundant order of crustacean life. The history of these two divisions, to adopt Agassiz's mode of representation, may be illustrated by two long tapering bands like two attenuated pyramids. The one has its broad base resting upon the existing now, and thinning away into the past, till at last it comes to a point. At a little interval the apex of the other begins, and gradually swells outward as it recedes, till the wide base terminates at the first beginnings of life.

But there are also some orders that would be best illustrated by a long line of nearly uniform breadth, extending from the first geologic periods to the present day. In other words, they seem to have retained during all time pretty much the same amount of development. I shall confine my notice of the carboniferous crustacea to the description of a single genus be-

the vertical greywackè slates of the Pentland Hills and Peeblesshire. Nothing can be more beautiful than the aspect of these fossils when first laid open, but the bright gleam eventually passes away on exposure.

longing to a family that seems to have begun during the period of the Lower Silurian, and still flourishes abundantly in existing waters.

The genus to which I refer is a well-known fossil in some parts of the Coal-measure series, and has been named *Cypris.* The shells of *cyprides* are very minute, considerably less than the heads of small pins (Fig. 20-1). They can be seen quite well, however, without the use of a magnifying power. In shape they resemble beans, and when seen scattered over a slab of shale, look much liker seeds than the relics of animal life. Yet, under this simple exterior, they concealed a somewhat complex organization. The little bean-shaped shells, which are all that now remains to us of their structure, formed the crust or outer shell in which their viscera were contained, and answered to the massive carapace and segments of the crab. They consisted of two valve-like cases fitting to each other, so as to resemble the united valves of a bivalve shell. From the upper end there were protruded through the opening between the valves a pair of slim jointed antennæ, each furnished at its point with a bundle of minute hair-like cilia (Fig. 20-2). These, when set in rapid motion, served to impel the creature through the water. The legs, four in number, were encrusted with the same hard membrane, and had the same jointed struc-

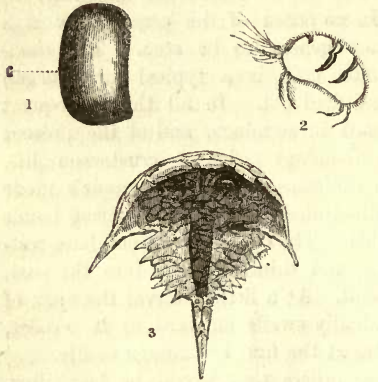


Fig. 20.

1. Carboniferous cypris, nat. size, and magnified.
2. Recent cypris, highly magnified.
3. Carboniferous king-crab (*Limulus trilobitoides*).

ture as those of our common shrimps and crabs. The foremost pair were pointed like the antennæ with fine hairs, the incessant action of which assisted the animal in swimming. Of the little, confluent, sessile eyes, the delicate branchia or gills, and all the complex internal structure of the nervous, circulating, and other systems, no trace has survived on the stone; but enough of the general external form is left to show us the true affinities of these organisms in the animated world of the present time. By studying the forms and habits of the cyprides that swarm in some of our ponds and marshes, a just conception is obtained of the structure and habitat of the animals that once occupied the minute bean-shaped shells, which lie by millions among the shales of the Carboniferous system. From such a comparison we infer, that just as the cyprides of to-day are fresh-water animals abounding among the green slime of stagnant pools, so, in past ages, they must have preserved with the same organization the same habits. And thus we arrive at the important conclusion that the strata in which the remains of cyprides abound must have been deposited in lakes or rivers. This gives us a key by which to interpret some of the changes of a geological system, and the ancient physical revolutions of large tracts of country.

The shales of the coal-measures sometimes contain the cypris cases in such abundance as to derive therefrom a sort of fissile structure. It should be borne in mind, however, that each animal may during its lifetime have possessed in succession several of these cases. Among the shell-bearing molluscous animals, the little shell which contains the creature in its youngest stages remains ever after as an integral part of the outer calcareous case. As the inhabitant grows, it continues to add band after band to the outer edge of the shell, each of which, whilst preserving the general symmetry and proportions of the whole structure, increases its dimensions in every way. Among the univalves, such, for example, as the turritella, so

common on our shores, the layers of growth succeed each other like the steps of one of those long spiral stairs that our feudal forefathers loved to build from the court-yard to the watch-tower of their castles. Each new layer exceeding in bulk its predecessors, adds a new step to the ascending pile, and thus the ever-widening mouth winds spirally upwards around the central pillar. The bivalves exemplify the same principle. The successive additions are made in a crescent form to the outer edges, and form those prominent concentric ridges so conspicuous on many of our commoner shells, such, for instance, as some of those in the genera *Astarte* and *Venus*.

But the architecture of the crustacea (and, of course, that of the cyprides) is conducted on a very different principle. Their houses admit of no additions or enlargements, and so, when the animals find themselves getting somewhat straitened, they retire to a sheltered spot, and there, separating the walls that hem them in, crawl out like soft lumps of dough. The outer membrane of the moulted animal quickly acquires strength and hardness, and in a day or two the renovated creature is as healthy and vigorous as ever. In this process it is not merely an external shell, like that of a mollusc, which is thrown off, but a veritable skin, so that when the old shell is abandoned it frequently could not be detected on a first glance to be empty, the outer crust of every leg and joint, and sometimes even of thin bristles, remaining just as in the living animal.

It is not unlikely that this process of moulting takes place annually in most of the crustacea, so that if we suppose a fossil member of the group to have lived six years, it would have left six crusts to be entombed in any deposits that might be forming at the time. Of course there would be many chances against all the six being preserved, but the possibility of at least several of them becoming fossilized should be borne in mind when we speculate on the abundance of such organisms in any geological formation.

I might refer to another very interesting group of crustacean animals known as the *Limuli*, or king-crabs, of which there were at least three representatives during the times of the English Carboniferous system (Fig. 20-^{3}). They are remarkable chiefly for their large crescent-shaped shield, their long sword-like tail, and their double pair of eyes, of which the outer ones are large, sessile, and compound, like those of the trilobites, while the middle pair are small, simple, and set close together on the forehead, like those of the single-eyed Cyclops in the old mythology. Altogether, with their shields, swords, watchful waking eyes, strong massive armour, and great size (for some of them measure two feet in length), they form a most warlike genus.

CHAPTER VI.

Carboniferous fauna continued—George Herbert's ode on "Man"—His idea of creation—What nature teaches on this subject—Molluscous animals—Range of species in time proportionate to their distribution in space—Two principles of renovation and decay exhibited alike in the physical world and the world of life—Their effects—The mollusca—Abundantly represented in the carboniferous rocks—Pteropods—Brachiopods—Productus—Its alliance with Spirifer—Spirifer—Terebratula—Lamellibranchs—Gastropods—Land-snail of Nova Scotia—Cephalopods—Structure of orthoceras—Habits of living nautilus.

Holy George Herbert, in one of the most remarkable odes of the seventeenth century, sang quaintly, yet nobly, of the dignity of man. He looked into the design and nature of the human heart, and saw there a palace that had been built for the abode of the Eternal. Deserted though it might be, broken down and in ruins, yet there still lingered a trace of its ancient glory, and the whole material world still testified to its inherent greatness. He looked abroad on the face of nature, and saw, in all its objects and all its movements, a continued ministration to man.

"For us the windes do blow;
The earth doth rest, heav'n move, and fountains flow.
Nothing we see, but means our good,
As our delight, or as our treasure:
The whole is, either our cupboard of food,
Or cabinet of pleasure.

"The starres have us to bed;
Night draws the curtain, which the sunne withdraws;
Musick and light attend our head.
All things unto our flesh are kinde
In their descent and being; to our minde
In their ascent and cause."

The idea is a very natural one, and is consequently as old as man himself. Human vanity is soothed by the reflection that all this varied world, with its countless beauties, has been designed and arrayed solely for the use of man. And yet, if we but think of it, such a view of creation, however natural and pleasing, is at the best but a narrow and selfish one. It assuredly finds no response in nature, and grows more and more out of fashion the further our investigations proceed. Nature teaches us that long ere man appeared upon the earth there were successive generations of living things just as now ; that the sun shone, and the waves rolled, and the wind blew, as they do to-day ; and that, on as lovely a planet as that whereon we dwell, there lay forests and prairies nursing in abundance animals of long-extinct forms ; lakes and rivers, haunted by creatures that find no representatives now ; and seas teeming with life, from the minute infusory up to the most unwieldy icthyosaur, or the most gigantic cetacean. And all this, too, ere a reasoning, intelligent being had been numbered among terrestrial creatures, and when, perhaps, each successive creation was witnessed by none save those "morning stars who sang together, and those sons of God who shouted for joy." The delight and comfort of the human race formed, doubtless, one of the many reasons why this globe was so bountifully garnished.[1] But the workmanship of a Being infinitely wise, and good, and powerful, could hardly have been other than complex and beautiful. That symmetry and grace which we see running as a silver thread through every part of creation, forms one of the charac-

[1] In connexion with this subject I have been often struck with a passage in St. Paul's Epistle to the Colossians, i. 16, "All things were created by him [Christ] and for [εἰς—with a view to, on account of] him." It is probable that these words, in their full meaning, cannot be understood by us. Yet they seem to point to Christ as at once the Creator, and himself the acme and design of creation ; and perhaps they may contain what hereafter shall prove the key to the mystery of creation. On this impressive and difficult subject the reader should refer to the closing chapter of Hugh Miller's *Footprints of the Creator*. See also M'Cosh on *Typical Forms*, 2d edit. p. 531.

teristics of the Almighty's mode of working. From the Fountain of all Beauty nothing unseemly or deformed can proceed. And so we find, away back among the ages of the past, that, though the material world might be less complete, it was not less beautiful than now. Nay, those bygone millenniums stood higher in one respect, for the eye of God rested upon their unsullied glory, and he pronounced them very good; but these last ages of creation are dimmed and darkened, and that Eye now watches a world trodden down by the powers of evil. There is profound truth in the sublime allegory of Milton that represents Sin girt round with clamorous hell-hounds, and the two grisly forms sitting at the farthest verge of purity and light, to keep the gates of darkness and chaos. With the introduction of moral evil into our planet came the elements of deformity and confusion. The geologist can go back to a time ere yet the harmony of nature had been broken. The Christian looks forward to a day when that harmony shall be again restored, and when guilt with all its hideous train shall be for ever chased away from the abodes of the redeemed.

Such thoughts as these sometimes arise in the mind of one who labours much among organic remains. By no class of fossils are they more vividly suggested than by those which we come next to examine—the various tribes of molluscous animals. This results from the high antiquity of these organisms, and the similarity of type which they have manifested in all ages. In the very earliest geological periods they exhibited the same symmetry of external form as now, the same beauty of structure, and apparently the same delicacy of colour. Nay, so closely did they resemble their existing congeners that we are seldom at a loss as to their affinities, and can refer them to their places in the scale of creation, and sometimes even to genera still living.[1]

[1] It must be admitted, however, that not a few of the identifications already made are somewhat suspicious. The natural tendency is to perceive resemblances—a tendency which even the most rigid science sometimes fails to control.

The geological ages saw many strange types of creation. One era, in especial, furnished reptiles which united in their structure the snout of the porpoise, the head of the lizard, the teeth of the crocodile, the paddles of the whale, and the backbone of the fish. Some displayed the long pliant neck of the swan, and others careered through the air on wings like those of the bat. But the molluscous tribes have never exhibited such aberrant forms. The existing classes and orders of the naturalist are still the same as those which flourished during the successive geological periods. Hence their value as evidence of physical changes in the ancient world. Hence, too, the conviction, forced upon the mind of the observer, that the conditions for the support of life never deviated much from those now in operation; that in place of all the varied beauty of the world having arisen for the use of man, it existed millions of years ere the breath of life had been breathed into his nostrils; that in fine, man is but a new-comer, a creation of yesterday.

There is another point suggested by the occurrence of mollusca in the Carboniferous system, to which it may be well to refer, namely, the curious, and as yet not wholly understood fact, that the range of animals in time is in some way proportionate to their range in space. In other words, it often happens (so often, indeed, as apparently to indicate a law) that the more widely diffused a genus is found to be at the present day, the farther back can we trace its remains into the geological ages. This fact probably depends upon causes, many of which are still unknown to us; but the following remarks may help the reader to a notion of the general bearings of the subject.[1]

In the profounder recesses of the ocean, the temperature

[1] The law is more especially exemplified by the mollusca, but it may eventually be found to characterize other classes. We, perhaps, see traces of it in the present distribution of the two most ancient orders of icthyic life—the placoids and ganoids.

remains more or less uniform all over the globe.[1] In these undisturbed regions there occur, along with corals and other humble animals, many kinds of mollusca, such as terebratulæ, craniæ, scissurellæ, &c. These are very generally found not to be confined to one province or limited district, but to flourish in every sea from Hudson's Bay to Hindustan. One of the causes of this wide distribution is the uniformity of temperature that characterizes the depths in which they live. They can migrate from one ocean to another, from the torrid zone to the polar circle, without experiencing any destructive change in the thermal conditions of their element. And provided only they meet with no barrier in the form of a lofty submarine mountain chain or profound abyss, and can secure the requisite food in their journey, we know no reason why some of these shells may not thus extend themselves over wide areas. Of the two species of *rhynconella* now living, one inhabits the depths of the icy sea, the other enjoys the warmer waters that lave New Zealand. The species, in this case, seem (for the fact cannot yet be accepted as fully proved) to occupy a more limited area, while the genus has a larger range.

Now, a genus widely diffused, and capable of enduring great differences in the temperature and other conditions of the ocean, would probably suffer least from any great physical changes. If all the sea at one locality were converted into land, the genus would be driven into other districts, and thrive as abundantly as ever; or, even supposing that it should become locally extinct, it would still be abundantly represented in other oceans of the globe. In the course of many ages, after

[1] The stratum of constant temperature runs in a wave-like form from pole to pole. In the arctic and antarctic oceans it is found at a depth of 4500 feet, whence it slopes upwards so as to reach the surface at the temperate zone on both sides of the equator. It then gradually sinks down in the warmer regions, till at the equator it is 7200 feet below the sea-level. There are thus one tropical and two polar basins separated by two wave-like circles, or, as a geologist would say, three synclinal troughs separated by two anticlinal ridges.

many such slow revolutions in the configuration of land and sea, the genus might perhaps become greatly reduced in numbers, until at length some final elevation of the sea-bed, or other change, might cause its total extinction. In the *rhynconella*, we perhaps see one of these genera in its last stage. Any great change in northern latitudes would probably destroy the arctic species, and a similar change around New Zealand might gradually extinguish the southern one.

Looking, then, from this point of view into the past history of life upon our planet, we see that such extinctions have often taken place. At first, many of these widely-diffused genera were created. They were represented by a large number of species as well as individuals, and ranged over all the oceans of the globe; but in tracing out their history, we mark one species after another passing away. Some of them lived for but a comparatively short period; others came in with the beginning and saw out the end of an entire geological system; but of all these early species there is not now a single one extant, though some of the genera still inhabit our seas. It is plain, therefore, that but for the operation of another principle, all the genera, too, would ere this have become extinct, for the whole can contain no more than the sum of its parts; and if these parts are destroyed the whole must perish simultaneously. As the species of certain genera died out, however, their places were from time to time filled up with new ones, yet the rate of increase became ever less and less than the rate of decrease, so that the numbers of such genera grew fewer with every successive period, and have reached their minimum in existing seas. There are instances, however, in which this ratio was reversed, the list of added species continually outnumbering that of the extinct, till the genus reached its maximum, when it either continued at that stage till the present day, or began slowly to decline.

In the physical world around us, we behold a perpetual strife between the two great principles of renovation and decay. Hills

are insensibly crumbling into valleys; valleys are gradually cut down, and their debris transported to the sea. Our shores bear witness to the slow but ever onward march of the ocean, whether as shattered cliffs worn by the incessant lashing of the surge, or as sand-banks and submerged forests that represent the wolds and holms of our forefathers. We mark, too, how the sediment thus borne into the main is sowing

"The dust of continents to be;"

while the slow elevation of large tracts of country, or the sudden upheaval of others, shows us by how powerful an agency the balance of land and sea is preserved, and how sometimes the paroxysm of an hour may effect a mightier change than the wasting and decay of a thousand years. We choose to call these two principles antagonistic, because in their effects they are entirely opposite; yet there is no discordance, no caprice in their operation. Each works out its end, and the result is the harmony and stability of the face of nature.

In the world of life, too, there seems to have been a double principle of decline and renewal. The natural tendency of species and genera, like that of individuals, has been towards extinction. Why it should be so we know not, further than that they are for the most part influenced by every change in physical geography. But they probably obey a still higher law which governs their duration, as the laws of vitality govern the life of an individual. If we are but slightly acquainted with the agency by which the degradation of land is counterbalanced, we are still more ignorant of the laws that preserve the balance of life. Creation is a mystery, and such it must for ever remain. So, too, are the principles on which it has been conducted. We can but mark their results. We see new species appear from time to time in the upward series of the geological formations, but they tell not whence they came. Of two genera created together at the beginning, one ere long died out,

but the other still lives; yet here there is assuredly nought like discordance or caprice. Nay, these two principles—death and creation—have been in active operation all through the ages, and the result is that varied and exquisitely beautiful world wherein we dwell.

The Mollusca are so named from the soft nature of their bodies, and are familiar to us as exemplified in the garden-snail and the shells of the sea-shore. The general type upon which they are constructed is that of an external muscular bag, either entire or divided into two, called the mantle, in which the viscera are contained. In most of the orders, they have likewise an outer hard calcareous shell, consisting of one or more parts. It is of course this shell alone that can be detected in the rocks, but by attending to the relations between the living animals and their shells, we ascertain the nature and affinities of the fossil species.

Few who ramble by the sea-shore, gathering limpets, whelks, and cockles, are aware how complex an anatomy is concealed within one of those brown discoloured shells. There are elaborate nervous and muscular systems—sometimes several hearts with accompanying arteries and veins—often dozens of rudimentary eyes—capsules which perform the function of ears—jaws, teeth, a strongly armed tongue—gullet, gizzard, stomach, liver, intestine, and complete breathing apparatus. The structure and grouping of these parts vary in the different genera and orders, and upon such variations is founded the classification of the naturalist. Thus, the mollusca of the highest class are called the *Cephalopoda*, or *head-footed*, because their feet, or rather arms, are slung in a belt round the head. They contain, among their number, the cuttle-fish, with its curious internal bone that shadows forth, as it were, the coming of the vertebrate type; and the nautilus, with its many-decked vessel of pearl. The second class is termed the *Gastropoda*, or *belly-footed*, as the genera embraced under it creep on the under side of the body,

which is expanded into a broad retractile foot. The common snail and whelk are familiar examples. The third class is formed by the *Pteropoda*, or *wing-footed*—delicate animals, found only in the open sea, and remarkable for a pair of wing-like expansions or fins on the sides of the mouth. The *Lamellibranchiata* form the fourth class, and receive their name from the laminated form of their *branchia*, or gills. They contain the two-valved shells, such as the oyster and scallop, and are one of the most abundant groups of animals on our coasts. The fifth class consists of the *Brachiopoda*, or *arm-footed* molluscs—a name given to them from their long spiral arms, once thought to be the instruments of motion, but now ascertained only to assist in bringing the food to the mouth. The sixth, and humblest class, has received the designation of *Tunicata*, from the thick bladder-like tunic, or sac, which supplies the place of an outer shell.

The geologist finds the remains of all these classes in the different rock-formations of the crust of the earth. They flourished so abundantly in the earliest seas, that the first geological period has sometimes been called the Age of Molluscs; and, during all the subsequent eras, they held a prominent place among the inhabitants of the deep. Let us look for a little at their development in the times of the Carboniferous system.

As the Carboniferous group of rocks exhibits the remains of ocean-bed, lake-bottom, and land-surface, so we find in it shells of marine, fresh-water and (though rarely) terrestrial mollusca. The marine genera greatly predominate, just as the shells of the sea at the present day vastly outnumber those either of lakes or of the land. In England they occur chiefly in the lower part of the formation, giving a characteristic stamp to the deep series of beds known as the mountain limestone. There they are associated with the corals and stone-lilies already described—all productions of the sea. In Northumberland, however, and

generally throughout Scotland, they occupy a somewhat different position. The great mountain limestone of central England gets split up into subdivisions as it proceeds northward, and beds of coal, full of land plants, become mingled with the ordinary marine strata. Sometimes we may find a group of brachiopods scattered over the macerated stem of a stigmaria; and the writer has himself collected a sigillaria in a limestone crowded with stone-lilies and *producti*. But this intermingling is still further carried on in the upper part of the series. The coal-beds, with their underclays and stigmaria rootlets, evidently representing ancient vegetation with the soils on which it grew, are succeeded by beds of limestone, full of marine mollusca; and these, again, are erelong replaced by sandstones, shales, and ironstones, charged with land-plants and fresh-water shells. To this curious blending of very different organic remains, I shall have occasion to refer more at large in a subsequent chapter. I mention it now as a sort of apology for the dryness of details which it is necessary to give, in order to complete our picture of the carboniferous fauna, and to understand the principles upon which the ancient history of the earth is deciphered.

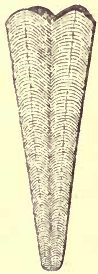


FIG. 21.

Of the *Pteropoda*, we have, as yet, but one carboniferous genus, the *conularia* (Fig. 21). It was a slim delicate shell, in shape an oblong cone, having four sides, finely striated with a sort of zig-zag moulding like that of the Norman arch. Each of the four angles was traversed along its whole extent by a narrow gutter-like depression, and this style of fluting, combined with the markings on the sides, imparted no little elegance to the shell. The conularia is not a common fossil. It has been found among the coal-bearing strata of Coalbrook-Dale, and was noticed long ago by Dr. Ure in his *History of Rutherglen.*

The *Brachiopoda* are bivalve molluscs, but unlike most other molluscs they are rooted to one spot, and destitute of any power of locomotion. Their shells are unequal, the dorsal, or upper valve, being smaller and usually more bulged out than the under or ventral valve, which in most species is prolonged at its narrow end into a kind of beak. In the terebratula this beak has a little circular hole, from which there emerges a short peduncle or stalk, that fixes itself firmly to a rock or other substance at the sea-bottom, and serves the purpose of an anchor and cable to keep the little vessel safely moored. When the shells are detached, these perforated ventral valves have so exactly the form of the old Roman lamps, "that they were called *Lampades*, or lamp-shells, by the old naturalists."[1] Other species, as the *lingulæ*, have no beak, and the long peduncle passes out between the valves, which are of nearly equal size, and have been compared to the shape of a duck's bill. In yet another genus, the *crania*, there is no peduncle, but the animal adheres by its lower valve, much like the oyster, and may often be seen clustered in groups on decayed sea urchins or other organisms, particularly in the chalk formation.

The internal structure of these animals is singularly beautiful. The inner surface of each valve is lined with a soft membranous substance, called the pallial lobe, the margin of which is set round with stiff hair-like bristles, that prevent the ingress of any foreign body likely to interfere with the play of the delicate filaments of the arms. These two soft lobes are furnished with veins, and supply the place of a breathing apparatus. The body of the animal occupies not quite a third part of the interior of its valves, and is situated at the narrow end. There are thus two distinct regions within the shell, separated from each other by a strong membrane, through the centre of which is the opening of the mouth. The smaller cavity next the hinge contains the viscera, and the outer larger one, the folded and ciliated arms.

[1] See the excellent *Manual of Mollusca*, by Woodward, p. 209.

These arms form one of the most characteristic features of the brachiopods. They are two in number, and proceeding from the margin of the mouth, advance into the outer empty chamber of the shell, and return upon themselves in spiral curves and folds. They are fringed with slim, flat, narrow filaments, set along the arm like teeth along the back of a fine comb. Though called arms, these long ciliated appendages are rather enormously protruded lips. The vibratory action of the fringes causes currents to set inwards towards the mouth, which is placed at the inner end or base of the arms. To support these long convoluted arms, many of the genera are furnished with slender hoops of hard calcareous matter, which are hung from the dorsal valve, and are still found within the shells of some of the most ancient fossil brachiopods.

The little visceral cavity contains the complex groups of muscles for opening and closing the valves, a simple stomach, a large granular liver, a short intestine, two hearts, and the centre of the nervous system. Without going into the details of these various structures, the reader will see that the brachiopoda are really a highly organized tribe ; and I am thus particular in the enumeration, partly that he may the better understand the mechanism of the carboniferous shells of that type, and partly that he may mark how the oldest forms of life, those that meet us on the very threshold of animated existence, were not low in organization, but possessed an anatomy as complex as it was beautiful.

Who that has ever wielded an enthusiastic hammer among the richly fossiliferous beds of the mountain limestone, does not remember with delight the hosts of delicately fluted shells that the labour of an hour could pile up before him? There was the striated productus, with its slim spines scattered over the stone. There, too, lay the spirifer with its broader plications, its toothed margin, and its deeply indented valve. Less common, and so more highly prized, was the slimly-ribbed rhynconella,

with its sharp, prominent beak, or perhaps the smooth, thin terebratula, with its colour-bands not yet effaced. These were pleasant hours, and their memory must dwell gratefully among the recollections of one whose avocations immure him throughout well-nigh the livelong year amid the din and dust of town—the *fumum et opes strepitumque Romæ.*

In the *productus* the dorsal valve is sometimes quite flat, while the ventral is prominently arched, and the shell resembles

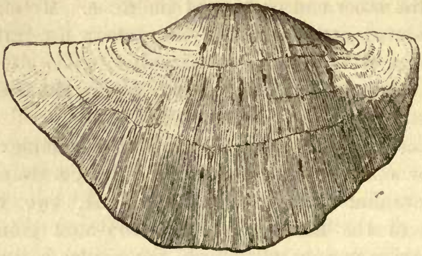


FIG. 22.—Productus giganteus.

a little cup with a flat plate of the same diameter placed over it. Usually, however, both the valves are concavo-convex, or arched in the same direction like two saucers placed within each other. The exterior surface of each valve is differently ornamented in the various species. A very common style of sculpturing is by a set of fine hair-like longitudinal ribs, diverging more or less regularly from the hinge line to the outer margin. In some species these ribs are wider, and are furnished with little prominent scars. In others (as *P. punctatus*) a set of semicircular ridges runs round the shell, narrowing as they converge from the outer lips to the centre of the hinge line, and bearing each an irregular row of small scars or tubercules. Some of the species are very irregularly ornamented into a sort

of wrinkled surface, in which the striæ seem, as it were, thrown over the valves in bundles at random.

The productus was furnished with slender hollow spines, which rose up from the surface of either valve, chiefly, however, about the hinge. In *P. spinosus* they were long and stout, like thin rush stalks, while in the smaller species they rather resembled stiff bristles. The use of these spines is not very well made out. As most of the producti appear to have been free, that is, without any peduncle fixing them to the sea-bottom, it has been conjectured that the spines, by sinking deep into the mud, may have served the place of a peduncle to moor the shell.

As regards size, the productus is very variable. You may gather some species in the young form, not larger than peas, while others may reward your search, having a breadth of six or eight inches (*P. giganteus*). But however much they may vary in dimensions, they usually remain pretty constant in their abundance, being among the most common fossils of the mountain limestone, and even of some limestones in the true Coal-measures ;[1] and that must be a poor stratum indeed which cannot yield you a bagful of producti.

The productus no longer ranks among living forms. It began during the times of the Upper Silurian system, lived all through the Old Red Sandstone, and attained its maximum of development in the seas of the Lower Carboniferous group. As the coal forests began to flourish, the productus seems to have waned ; but it is still sometimes found in considerable numbers in the ironstones and limestones intercalated among the coal seams of northern England and central Scotland. In the period which succeeded the coal, that, namely, of the Permian, it seems to have died out altogether, at least no trace of its remains have as yet been detected in strata of a later age. But whilst it lived, the productus must have enjoyed a wide range

[1] See the table given below in Chap. X.

of climate, for its valves have been found by thousands both in the old world and in the new. I have seen several that were brought from the hills of China, and they occur likewise in Thibet. Specimens have been brought, too, from the warm plains of Australia, and from the snows of Spitzbergen.

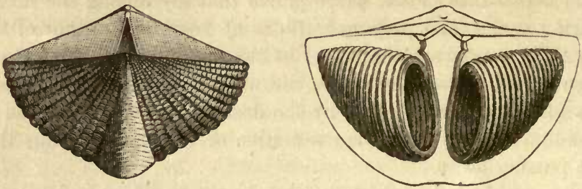
In looking over the fossils that lie grouped along beds of the mountain limestone, there are two forms that we find almost invariably side by side—the productus and the spirifer. They seem to have begun life together, or rather, perhaps, the spirifer is somewhat the older brother. They voyaged through the same seas, and anchored themselves to the same ocean-bed, sometimes among mud and ooze, and often among bowers of corals and stone-lilies. They visited together the most distant parts of the world, from China to Chili, and from Hudson's Bay to New Zealand. I have sometimes laid open fragments of limestone where they lay thickly clustered as though they had ended a life of friendship by dying very lovingly together. But after all the varieties of the productus had died out, some species of the spirifer still lived on, and it was not until the period of the lias that they finally disappeared. I remember meeting with one of these latest spirifers in the course of a ramble in early morning along the shores of Pabba, one of the lone sea-girt islands of the Hebrides, where the Scottish secondary rocks are represented. The beach was formed of low shelving reefs of a dark-brown micaceous shale, richly charged with the characteristic fossils of the Lias—ammonites, belemnites, gryphææ, pectines, &c. In the course of the walk I came to a lighter coloured band, with many reddish-brown nodules of ironstone, but with no observable fossils. A search, however, of a few minutes disclosed a weathered specimen, near which a limpet had made good its resting-place ; and this solitary specimen proved to be one of the last lingering spirifers (*S. Walcottii*). The form struck me at once as a familiar one, and recalled the fossils of the mountain limestone. It may

seem a puerile fancy, but to one who had lately been working among palæozoic rocks, and remembered the history of the spirifer, there was something suggestive in the loneliness of the specimen. With the exception of one or two other organisms (as *rhynconella*), it was by far the most ancient form of the deposit. Its family had come into the world thousands of years before that of the large pinnæ that lay among the neighbouring shales, and perhaps millions of years before that of the gracefully curved ammonites. But the family was nearly extinct when these shales were being thrown down as sandy mud, and this wasted specimen, worn by the dash of the waves, seemed in its solitariness no inapt representative of an ancient genus that was passing away.

The spirifer received its name from the two highly developed spiral processes in the interior of the shell attached to the dorsal valve. They were hard, like the substance of the shell, and sprang from near the hinge, each diverging outwards to near the border of the valve. They resembled two cork-screws, but the loops were much closer together. These coiled calcareous wires almost filled the hollow of the shell (Fig. 23), and ample support was thus afforded to the filamentous arms. In recent brachiopods, these arms do not always strictly follow the course of the calcareous loops. Among palæozoic genera the case may have been similar, so that the complex calcareous coil of the spirifer may not perhaps indicate a corresponding complexity of the arms. But none of the few recent forms exhibit anything like the coiled processes of the spirifer.

The Carboniferous system of Great Britain and Ireland is stated to have yielded between fifty and sixty species of spirifers. Of course, in such a long list the gradations are sometimes very nice, and to an ordinary eye imperceptible, but there exist many marked differences notwithstanding. The general type of the spirifers is tolerably well defined. They had both valves arched outwards, not concavo-convex as in the productus.

Their hinge-line, like that of the latter shell, ran in a straight line, and their dorsal valve was raised along its centre from hinge to outer margin, into a prominent ridge, while in the ventral valve there was a furrow exactly to correspond. Most of the species were traversed by sharp ribs radiating from the



b

FIG. 23.—Spirifer hystericus. *b* Interior of the same, showing the arrangement of the spiral arms.

centre of the hinge-line like those on the surface of the common cockle. But some were quite smooth, retaining only the high lobe in the centre, such as *S. glaber*. In a noble specimen figured by M'Coy [1] under the name of *S. princeps*, the valves are covered with broad plaits that sweep gracefully outward from the centre of the hinge-line.

The spirifers vary more in form than in external ornament. Some are triangular, others nearly semicircular, others long and attenuated. In some species (as the *S. glaber*), the central ridge is very prominent, taking up about a third of the entire area of the shell, and thus giving it a trilobed appearance. In others (as *S. symmetricus*) it is less marked, and bears a minor furrow down its centre; while in yet a third class (as in some specimens of *S. trigonalis*) the median fold scarcely rises above the ribs that are ranged on each side.

These old shells probably anchored themselves to the sea-bottom by means of a thin peduncle, and lived by the vigorous

[1] *Carb. Limest. Foss. of Ireland,* pl. 21, fig. 1.

action of those complex fringed arms, whose screw-like skeleton still occasionally remains, and which conveyed to the mouth the animal substances that served as food.

I shall refer to but one other brachiopod of the carboniferous rocks, interesting both as one of the forms of life still living in our seas, and as exhibiting, after the lapse of such a vast interval, the form of the coloured bands which adorned it when alive. It is called *Terebratula hastata*; a slim delicate shell like its representatives of the present day, narrow at the beak, and bulging out towards the outer margin, which is slightly curved. The surface is smooth, and in the older specimens has numerous concentric layers of growth, especially marked near the margin. The stripes of colour radiate from the beak outwards, and though the tint which once brightened them is no longer visible, it may be that the vessel of the little terebratula, which lay anchored perhaps fifty fathoms down, was well-nigh as gaily decked as a felucca of the Levant. But the existence of these colour-bands is not merely interesting; the geologist can turn it to account in investigating the physical conditions of an ancient ocean. The late Professor Edward Forbes, after a careful series of investigations in the Mediterranean, brought to light the fact, that below a depth of fifty fathoms shells are but dimly coloured, and hence he inferred, from the numerous coloured shells of the carboniferous limestone, that the ocean in which they lived was not much more than fifty fathoms deep.[1]

FIG. 24.—Terebratula hastata.

The *lamellibranchiate* bivalve shells of the British Carboniferous system, so far as yet discovered, number about 300

[1] Similar coloured bands are found even in the Lower Silurian, *e.g.*, on *turbo rupestris* (Murchison's *Siluria*, p. 194), while on many of the carboniferous gastropods and lamellibranchiate bivalves, they are of frequent occurrence.

species, belonging to genera some of which are still familiar to us. There were the *pectens* or *scallops*, the *pinnas* with their beards of byssus, the *cardiums* or cockles, the *mytili* and *modiolæ* or mussels, all sea-shells. Then among the fresh-water bivalves we can detect several species of the *unio* or river mussel, that perhaps displayed valves as silvery in their lining as those of our own pearl-mussels. But with these well-known forms there co-existed some that no longer survive. Such was the *conocardium*, a curious form that looks like a *cardium* cut through the middle, with a long slender tube added to the dismembered side (Fig. 25). The *aviculopecten*, a shell allied to our common

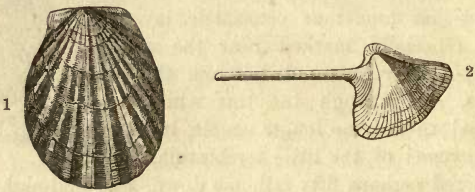


FIG. 25.—CARBONIFEROUS LAMELLIBRANCHS.
1. Aviculopecten sublobatus (showing colour-bands). 2. Conocardium aliformis.

scallop, and sometimes showing still its colour-bands (Fig. 25), and the *cardinia* or *anthracosia*, a small bivalve that abounds in the shales and ironstones of our coal-fields, along with nautili, producti, and conulariæ at Coalbrook Dale, and with a thin leaf-like lingula at Borrowstounness.

The *Gastropods* of the carboniferous rocks in the British Islands embrace from twenty-five to thirty genera, with upwards of 200 species. Here, too, we can detect some forms that have not yet passed away. The *trochus*, so universally diffused over the globe at the present day, also lived in the palæozoic seas. Its companions, the *natica*, the *turritella*, and the *turbo*, likewise flourished in these ancient waters. Among the genera now extinct we may notice the *euomphalus*, with its

whorls coiled in a flat discoidal form ; and the *bellerophon*, with its simple coiled shell, resembling in general form the nautilus. The gastropods are numerously represented in our gardens and woods, by the various species of the snails, animals that have a most extensive distribution over the world, and number probably not much under two thousand species. For a long time it was matter of surprise that no such land shells had ever been detected in the carboniferous rocks. Trees and forests had been turned up by the hundred, but never a trace was found of any air-breathing creature. From this fact, and from the enormous amount of vegetable matter preserved, it was once

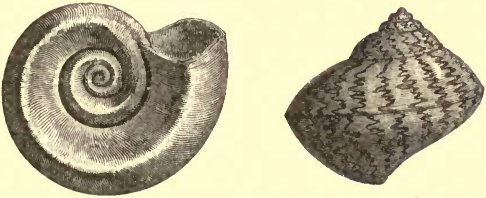
1  2

FIG. 26.—CARBONIFEROUS GASTROPODS.
1. Euomphalus pentangulatus. 2. Pleurotomaria carinata (showing colour-bands).

hastily inferred that the atmosphere of that ancient period must have been uncongenial to air-breathers ; that, in short, it was a dense heated medium of noxious carbonic-acid gas, wrapt round the earth like a vast mephitic exhalation, favourable in the highest degree to the growth of vegetation, yet deadly as the air of Avernus to all terrestrial animals. But this notion, like most other bold deductions from merely negative evidence, has had to be abandoned, for traces of air-breathers have at last been found. Among these, not the least interesting is the shell of a *pupa*, a sort of land-snail, which Sir Charles Lyell detected, along with the bones of a small reptile, embedded in the heart of an upright sigillaria stem in the carboniferous

rocks of Nova Scotia. Small as was the organism, the evidence furnished by it proved scarcely less valuable than if it had been a large mammal that might have afforded material for weeks of study. The similarity of the shell to existing forms, showed that the ancient carboniferous forests had at least one race of air-breathing creatures among their foliage, and that the atmosphere of the period could have differed in no material point from that of the present day, for as the snails breathe by lungs, and require, consequently, a continual supply of oxygen to support respiration, they could not have existed in an atmosphere charged with carbonic acid.

The *Cephalopods*, or highest class of mollusca, are represented among the British carboniferous strata by seven genera. Of these the most characteristic is the *orthoceras*, so named from its shell being like a long straight horn. When the animal was young it inhabited a single-chambered shell like that of many of the gastropods, but as it increased in size and prolonged its shell in a straight line, it withdrew from the first

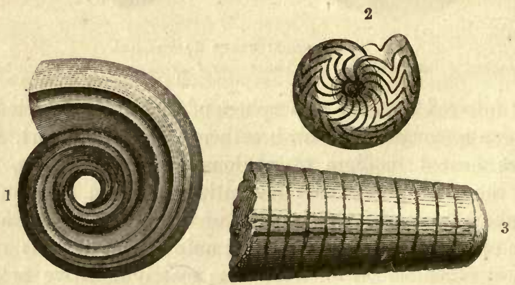


FIG 27.—CARBONIFEROUS CEPHALOPODS.
1. Nautilus Koninckii. 2. Goniatites crenistria. 3. Orthoceras laterale (fragment).

occupied chamber. This was partitioned off by a thin wall called a *septum*, through the centre of which a tube ran to the narrow

end of the shell (Fig. 27). As the creature grew, chamber after chamber was in this way formed, each of them quite air-tight, and traversed by the central tube. Suppose a graduated series of diminutive watch-glasses to be pierced by a long tapering glass-tube in such a way that they should have their convex faces towards the narrow end of the tube, and be arranged at short intervals, the smallest one placed near the point of the tube, and the largest a little below the wider end. Suppose, further, that this piece of mechanism were placed within another tube tapering to an obtuse point, and that the edges of the watch-glasses fitted tightly to the inner surface of this larger tube. Such would be a rough model of the structure of the orthoceras.

The inner tube that traverses the centre of the chambers from end to end of the shell is called the *syphon*, but its uses are very problematical. At one time naturalists inclined to regard it as intended to be filled with fluid, which, by expanding the membrane of the tube, would compress the air in the chambers, and thus, increasing the specific gravity of the animal, enable it to sink to the bottom. In this way, by emptying or filling the syphonal tube, the orthoceras might have risen rapidly to the surface of the deep, or sunk as swiftly to the bottom. But this view, so pretty that one wishes it were confirmed, must be regarded as at least doubtful. The orthoceras more probably owed its power of progression to the action of a funnel connected with the breathing apparatus, whereby jets of water were squirted out that drove the shell rapidly along. The use of the air-tight chambers was, perhaps, to give buoyancy to the shell so as to make it nearly of the same specific gravity as water. Such a provision must have been amply needed, for Professor Owen mentions an orthoceras from Dumfries-shire that measured six feet in length, and similar gigantic specimens have been found in America. Unless the chambers in these shells had been air-tight, the animals that inhabited them would have been held down about as firmly to

one spot as if they had been tied to a sheet-anchor. No mollusc could have possessed much locomotion with so ponderous a tail, six feet or more in length, to drag after it. But this inconvenience was obviated by the simple plan of having the chambers close, and filled with nitrogen or other gas evolved by the chemistry of the inmate. The shell, in this way, acquired no little buoyancy, and probably stood up like a church spire, the animal keeping close to the bottom to lie in wait for any hapless mollusc or trilobite that might chance to come in its way.

The *nautilus* (Fig. 27), which still lives in our seas, occurred likewise in those of the Carboniferous period. It was a coiled shell; in truth, just an orthoceras rolled up in one plane like a coil of watch-spring. An allied form, called the *goniatite* (Fig. 27), had the margins of its septa of a zig-zag form, like the angles of the wall round a fortified town. When the thin outer coating of the shell is removed, the ends of these partition-walls are seen to form strongly-marked angulated sutures or joints, where they come in contact with the shell. Hence the name of the genus—*angled* shell.

All these animals were predaceous. They did not confine themselves to the lower forms of life, polyps and medusæ, nor even to the humbler tribes of their own sub-kingdom, but hesitated not to wage war with creatures greatly higher in the scale of creation than themselves, such as the smaller fishes. They swarmed in the palæozoic seas, and well merited the title of scavengers of the deep, that has been bestowed on the sharks of our own day. They seem to have performed a function now divided partly among the fishes and partly among the higher gastropodous molluscs. And accordingly we find that as these latter tribes increased, the orthoceratites, and goniatites, and ammonites waned. At the present day, of all the palæozoic cephalopods there remains but one—the nautilus;[1] and so rare

[1] And perhaps even that is doubtful, for it is not unlikely that after all, the palæozoic

is it, that up to the year 1832, all sorts of fanciful notions existed as to its nature and functions. In fact, the nautilus was a sort of myth which any naturalist could dress up as he chose, much as the old poets used to picture the ship Argo. A specimen was at length procured and intrusted to the examination of Professor Owen, by whom its anatomy was studied, and afterwards philosophically described in an elaborate monograph. Then, for the first time, did geologists obtain a true notion of the nature of those siphonated shells, which lie grouped by hundreds in the palæozoic and secondary formations. Yet we still want an account of the habits of the nautilus. The older naturalists alleged that it could at pleasure rise to the surface or sink into the depths of the ocean; that it could spread out its fleshy arms and float across the waves or draw them in, capsize the little vessel, and so return to a creeping posture among the sea-weed at the bottom. These statements may to some extent be true, for the chambers of the nautilus shell must impart great buoyancy to it. But in the meantime the story of the sailing propensities of the animal is derived from a sort of mythic age, and must be viewed with some little suspicion. Until further observations are made, we shall neither fully understand the economy of the nautilus nor the habits of the cephalopods of the palæozoic seas. But the day is probably not far distant when such doubts will be set at rest, and we shall know whether the nautili and orthoceratites swam in argosies over the surface of the ocean, or, keeping ever at the bottom, left the waves to roll far above them, unvaried save perchance by some floating sea-weed or drifted tree.

nautili may belong in reality to another genus. Twenty years hence will probably see no little change on our present identifications.

CHAPTER VII.

Classification of the naturalist not always correspondent with the order of nature — Incongruous grouping of animals in the invertebrate division—Rudimentary skeleton of the cephalopods—Introduction of the vertebrate type into creation—Ichthyolites of the carboniferous rocks—Their state of keeping—Classification of fossil fishes—Placoids—Ichthyodorulites—Ganoids—Their structure exemplified in the megalichthys and holoptychius—Cranium of megalichthys—Its armature of scales—Microscopic structure of a scale—Skeleton of megalichthys—History of the discovery of the holoptychius—Confounded with megalichthys—External ornament of holoptychius—Its jaws and teeth—Microscopic structure of the teeth—Paucity of terrestrial fauna in coal measures—Insect remains—Relics of reptiles—Concluding summary of the characters of the carboniferous fauna—Results.

The organic remains hitherto described belong to that large division of the animal kingdom instituted by Lamarck, to comprehend all those whose internal structure is supported by no vertebral column, and which are hence termed invertebrate. They are for the most part protected by a hard outer covering, or exo-skeleton, which assumes many different modifications. We have seen it in the calcareous cells of the little net-like fenestella, in the geometric cup of the stone-lily, in the double case of the cypris, and in the shells of the mollusca. But the order of nature does not always exactly correspond with the classification of the naturalist. His system must necessarily be precise, formal, and defined. One tribe ends off abruptly, and is immediately succeeded by another, with different functions and structure, and dignified with a separate name. But in the order of creation, such abrupt demarcations are few, for if they exist in the present economy, they can not unfrequently be filled up from the existences of the past. There is usually a shading off of one class into another, like the blending of the tints of

sunset, and it often baffles all the skill of the profoundest anatomist, by drawing a distinct line, to pronounce where the one division actually ends and the other begins. Any name, therefore, which is intended to embrace a large section of the animal kingdom, must ever be more or less arbitrary. It will extend too far in one direction, and embrace organisms which might be classed in a different section. It will probably not extend far enough in another, and thus leave beyond its pale animals possessing strong affinities to the majority of those included under it. More especially is this true of every system of classification that proceeds upon the modifications of a single feature, or upon mere negative resemblances. Suppose, for instance, that it were proposed by some highly systematic individual to divide the inhabitants of our country into two great classes—the bearded and the beardless. In the latter category he would arrange all the more quiet and orderly portion of the community, with perchance a tolerable intermixture of rogues. The bearded group would present a most motley array—from the fierce-visaged heroes of the Crimea to the peaceable stone-mason or begrimed pitman—all brought into one list, and yet agreeing in no single feature save that of being like Bully Bottom the weaver, "marvellous hairy about the face." But Lamarck's invertebrate division of the animal kingdom presents a grouping of yet more diverse characteristics, as cannot fail to be confessed when we recollect that it embraces among its members the microscopic monad, the coral polyp, the lobster, the butterfly, the limpet, the nautilus, and the cuttle-fish. Cuvier's threefold grouping of the division into *mollusca*, *articulata*, and *radiata*, has now supplanted the old name, though the latter is still retained as a sort of convenient designation for all the animals below the vertebrate type.

The most highly developed of the recent cephalopods exhibit a true internal skeleton, in the form of a strong oblong bone, on which the body is hung. In this respect they occupy a sort

of intermediate place between the lower molluscs on the one hand, and the lower fishes on the other. Theirs is not a vertebral column, but rather, as it were, a foreshadowing of it; not, however, as a link in some process of self-development from mollusc to fish, for these higher cephalopods do not appear to have been created until fishes and reptiles had lived for ages. The vertebrate type has been traced well-nigh as far back into the past as we have yet been able to penetrate. Once introduced, it has never ceased to exist, but in the successive geological ages has been ever receiving newer and higher modifications, reaching its perfection at length in man. The vertebrate form of structure fulfils the highest adaptations of which terrestrial beings seem capable. We can hardly conceive of corporeal existence reaching a more elevated stage of development, save in thereby becoming less material, and receiving an impartation of some higher element. The vertebrate animals display not merely the most complexly organized structures, but manifest in their habits the workings of the higher instincts and affections. Among the invertebrate tribes the propagation of the species is, in the vast majority of cases, a mere mechanical function, like that of feeding or respiration, and the eggs once deposited, the parent has no further care of her young. But among the vertebrated animals, on the other hand, the perpetuation of the race forms the central pillar round which the natural affections are entwined. It parcels out every species into pairs, in each of which the mates are bound together by the strongest ties of attachment. It gives birth, too, to that noble instinct which leads the mother to expose her own life rather than suffer harm to come to her offspring. It produces, at least in man, that reciprocal attachment of offspring to parent, from which springs no small part of all that is holiest and best in this world. These attributes, to a greater or less extent, belong to all the vertebrate animals, from the fish up to man. In looking over the relics of animal life in the earlier geological formations, we are apt, as we gaze

on the massive jaws and teeth, the strong bony armour, and the sharp, barbed spines, to think only of a time of war and carnage, when the larger forms preyed upon the smaller, or ruthlessly sought to exterminate each other. Yet should we not remember, that with all these weapons and instincts of self-preservation there were linked attributes of a nobler kind; that the earliest vertebrate remains point to the introduction—though perhaps in but a rudimentary form—of self-sacrificing love into our planet? The march of creation from the first dawn of life has ever been an onward one, as regards the development not only of organic structure but of the social relations; and if it be true that physical organization finds its archetype in man, it is assuredly no less so that in him too we meet with the highest manifestation of those instincts which, by linking individual to individual, have ever marked out the vertebrate tribes of animals from the more machine-like characteristics of the invertebrate.

We pass now to the vertebrate animals, and shall look for a little into the general grade and organization of the fishes that characterized the carboniferous rivers and seas.

A collection of the ichthyolites of the carboniferous rocks presents almost every variety in the mode of preservation. The smaller species are frequently found entire, and show their shining scales still regularly imbricated as when the creatures were alive. The larger forms seldom occur in other than a very fragmentary condition. The limestones yield dark-brown or black, oblong, leech-like teeth, which are found on examination to be those of an ancient family of sharks. The shales are often sprinkled over with glittering scales and enamelled bones. Some of the coals and ironstones yield in abundance long sculptured spines, huge jaws bristling with sharp conical teeth, and detached tusks, sometimes five or six inches long. In short, the naturalist who would decipher the ichthyology of the Coal formation, finds before him, in the rocks,

not a suite of correctly arranged, and carefully preserved skeletons, but a set of disjointed, unconnected bones; here a tooth, there a scale, now a jaw, now a dermal plate, all mingled at random. And yet, though the evidence lie in this fragmentary state, our knowledge of these ancient fishes is far from being correspondingly meagre. To such precision has the science of comparative anatomy arrived, that a mere scale or tooth is often enough to indicate the nature and functions of the individual to which it belonged, and to establish the existence in former times of a particular class or order of animals. Thus the smooth rounded teeth of the mountain limestone are found to present both externally and internally a close resemblance to the hinder flat teeth of the sole living cestraciont (*C. Philippi*); and we hence learn that a family of sharks, now all but extinct, abounded in the palæozoic seas. The occurrence of a set of dark, rounded little objects, which by the unpractised eye would be apt to be mistaken for pebbles, is in this way sufficient at once to augment our knowledge of the various animals of the Carboniferous period, and to establish an important fact in the history of creation.

Of the four great Orders into which Agassiz[1] subdivided the class *Pisces*, the Placoids and Ganoids, agreeing on the whole with the cartilaginous fishes of Cuvier, occur abundantly in the palæozoic rocks, while the Cycloids and Ctenoids, answering to

[1] The classification of Agassiz, which is certainly not a little arbitrary and artificial, has been altered by Müller, a distinguished German anatomist, whose arrangement has been modified again by Professor Owen. See Owen's *Lectures on Comparative Anatomy*, vol. ii. p. 47. There is far from anything like unanimity on the subject. Every naturalist thinks himself at liberty to modify and restrict the groupings of his predecessors or contemporaries, sometimes without condescending to give synonyms or any clue by which one may compare the rival classifications. The geological student cannot engage in a more sickening task than that of ranging through these various arrangements, and he must possess some self-command who can refrain from throwing up the search in disgust. The best way of progressing is to select some standard work and keep to it, until the characteristics of the genera and families have been mastered, and as far as possible, verified from actual observation. After such preliminary training, the student will be more able to grope his way through the "chaos and dark night" of synonyms and systems.

Cuvier's osseous fishes, began in the Secondary formations, and are found in all subsequent deposits. The two former reached their maximum in the earlier geological ages, and have been gradually dwindling down ever since, till now they are represented by comparatively few genera; the two latter are emphatically modern orders; they have been constantly increasing in numbers since their creation, and swarm in every sea at the present day. The carboniferous ichthyolites belong, of course, only to the two first-mentioned orders—the placoids and ganoids.

The Placoid, or *Plagiostome* fishes, are familiar to us all as exemplified in the common thornback and skate of our markets. They are covered with a tough skin, which either supports a set of tuberculed plates as in the thornback, or a thick crop of small rounded bony points or plates, as in the shagreen of the sharks. The head consists of a single cartilaginous box. The spinal column is likewise formed of cartilage, built up in the higher genera of partially ossified vertebræ. The tail is heterocercal or unequally lobed, inasmuch as the spinal column, instead of ending off abruptly as it does in the herring, trout, and all our commoner fishes, passes on to the extreme point of the upper half of the tail. This is a noticeable feature, for it has been found to characterize all the fishes that lived in the earlier geological periods. The fins are often strengthened by strong spines of bone, which stand up in front of them and serve the double purpose of organs of progression and weapons of defence. The teeth vary a good deal in form. In the larger number of existing placoids they are of a sharp cutting shape, often with saw-like edges. Among the sharks they run along the jaws in numerous rows, of which, however, only the outer one is used, those behind lying in reserve to fill up the successive gaps in the front rank. The teeth do not sink into the jaw, as in the ganoids, but are merely bound together by the tough integument which forms the lips. Another form of tooth, abundant among the ancient placoids, and visible on some of those

FIG. 28.—Ctenacanthus hybodoides. (Egerton.

at the present day, shows a smooth rounded surface, the teeth being closely grouped together into a sort of tessellated pavement which, in the recent species, runs round the inner part of the jaws, while a row of conical teeth guards the entrance of the mouth.

The animals which possess these characteristics include the various tribes of the sharks and rays, and form the highest group of fishes. They are all active and predaceous, frequenting every part of the ocean where their prey is to be found. The formidable spines and hideous "chasm of teeth" belonging to the bulkier forms, render them more than a match for any other denizens of the deep, and thus they reign in undisputed supremacy—the scourge of their congeners, and a terror to man.

The seas of the Carboniferous era abounded with similar predaceous fishes, some of which must have been of enormous size. An entire specimen has never been obtained; nor, from the destructible nature of the animal framework, can we expect to meet with one. But the hard bony parts of the animals, those capable in short of preservation in mineral accumulations, are of common occurrence in the mountain limestone beds and even among the coal seams. The dorsal spines or *ichthyodorulites*, are especially conspicuous (Fig. 28). They stood up along the creature's back like masts, the fin which was attached to the hinder margin of each, representing

the sail. The spine could be raised or depressed at pleasure, its movements regulating those of the fin, much as the raising or lowering of the mast in a boat influences the lug-sail that is attached to it. The general form of these spines was long, tapering, and more or less rounded. But they assumed many varieties of surface ornament. Some species were ribbed longitudinally, and had along their posterior concave side a set of little hooks somewhat like the thorns of a rose. Others seem to have been quite smooth, and of a flattened shape, with a thick-set row of sharp hooks down both of the edges, like the spine on the tail of the sting-ray of the Mediterranean. Such weapons have considerable resemblance to the barbed spear-heads of savage tribes, and it is certain they were intended to act in a similar way, as at once offensive and defensive arms. The toothed spines of the sting-rays are still used in some parts of the world to point the warrior's spear and arrow. Is there not something suggestive in the fact that these stings, after having accomplished their appointed purpose as weapons of war in the great deep, should come to be employed over again in a like capacity on the land; and that an instrument, which was designed by the Creator as a means of protecting its possessor, should be turned by man into an implement for gratifying his cupidity and satiating his revenge? Other ichthyodorulites are elegantly ornamented by long rows of tuberculed lines arranged in a zig-zag fashion, or in straight rows tapering from base to point. In all there was a blunt unornamented base, which sank into the back and served as a point of attachment for the muscles employed in raising or depressing the spine. In some specimens the outer point appears rounded and worn, the characteristic ornament being effaced for some distance—a circumstance which probably indicates that these fishes frequented the more rocky parts of the sea.[1]

[1] See Egerton, *Quart. Jour. Geol. Soc.*, vol. ix. p. 281.

The placoid teeth of the carboniferous rocks show the usual forms of the order. Some of them are sharp and pointed, as those of the hybodonts; others have a smooth, rounded, or plate-like form, as in the cestracionts. The latter often show a dark brilliant surface, and might be readily enough mistaken for well-worn pebbles. In the oblong rounded teeth of *psammodus* the surface is densely covered with minute points like grains of sand, whence the name of the genus. These teeth, when sliced and viewed under the microscope by transmitted light, exhibit a complex reticulated internal structure.

Agassiz' second great Order of fishes is named Ganoid, from a Greek word signifying brightness, in allusion to the brightly enamelled surface of their dermal covering. They differ from the placoids in having their outer surface cased in a strong armature of bone, which is disposed either in the form of large overlapping plates, as among the strange tortoise-like fishes of the Old Red Sandstone, or as thick scales, which are either placed at intervals, as along the back and sides of the sturgeon, or closely imbricated, as in the stony-gar (*lepidosteus*) of the American rivers. This strong, massive skeleton constitutes in many genera the sole support of the animal framework, the inner skeleton being of a gristly cartilaginous kind, like that of the skate. On this account traces of the vertebral column are by no means abundant among the older formations. But as the ganoids form a sort of intermediate link between the placoid or gristly fishes on the one hand, and the bony fishes on the other, they are found to present in their different genera examples of both these kinds of structure. Thus, the skeleton of the sturgeon consists of a firm cartilage, out of which the vertebræ are moulded, so that this fish was at one time ranked with the sharks in the cartilaginous tribe of Cuvier. The skeletons of some of the older ganoids (as *holoptychius*), on the other hand, manifest such a decidedly osseous structure, with sometimes so much of a reptilian cast, that the bones were at first referred to some huge

extinct saurians. The head of the ganoid fishes is encased in a set of large massive plates of bone, and the jaws are furnished with several rows of small sharp teeth, intermingled with a less numerous but larger-sized and more formidable kind. The interior of the mouth likewise displayed in many ancient genera groups of palatal teeth, so that the dental apparatus of these animals must have been very complex and complete. The tail in all the older ganoids was heterocercal, like that of the sharks, the lobes being not unfrequently densely covered with minute overlapping scales of bone—a peculiarity which also extended to the fins. But the fins were sometimes strengthened in another way by having the foremost ray greatly thickened and enlarged, so as to form a stiff spine like the ichthyodorulites of the placoids. The whole of the external surface of these ganoidal fishes glittered with enamel, and was usually sculptured in the most graceful patterns or ornamented with fine lines and punctures so minute as to be almost invisible to the naked eye. Every plate, scale, fin-ray, nay, the very lips exhibited the characteristic enamel mottled over with the style of ornament peculiar to the species. And when we think we have exhausted the contemplation of these beauties, it needs but a glance through an ordinary microscope to assure us that the unassisted eye catches only a superficial glimpse of them. The more highly we magnify any portion of these old-world mummies, the more exquisite does its structure appear.

In the carboniferous rocks of Great Britain, upwards of forty species of ganoids have been detected. They have a wide range in size, the smallest measuring scarce two or three inches, while the largest, to judge at least from the bones which they have left behind, must have reached a length of twenty, or perhaps even thirty feet. The lesser genera (Fig. 29) were characterized by small, angular, glossy scales, usually ornamented either with a very minute punctulation, or with fine hair-like lines which sometimes exhibited the most complicated patterns.

The scales were likewise occasionally serrated along the exposed edges—a style of ornament which gives no little richness to the aspect of the dermal covering. The fins, closely imbricated with small angular scales of bone, sometimes displayed a striated ray in front, but this neither possessed the strength nor the formidable aspect of the corresponding spine among the placoids. The head was encased in a set of bony plates fitting tightly into each other, and ornamented with various patterns according to the species. The teeth were very

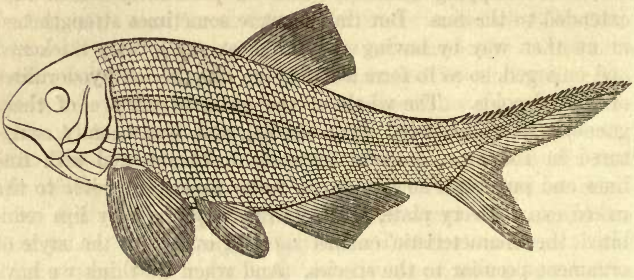


FIG. 29.—Amblypterus macropterus (a Carboniferous ganoid).

small and fine, resembling the bristles of a brush, but in at least some species intermingled with teeth of a larger size. The minute style of dentition in these smaller fishes has been thought to indicate their habit of keeping to the bottom of the water and feeding on the soft decaying substances lying there. Nowhere have I seen the small rhomboidal scales of the *palæoniscus* so abundant as among dark shales charged with cypris cases and fragments of terrestrial plants, and on such occasions the idea has often occurred that these graceful little fishes, like the *amia* of the American rivers, may have fed on the cyprides that swarmed along the bottom of the estuary.

Scattered over the fresh-water limestones, ironstones, and shales, or crowded together along the upper surface of some of

the coal-seams, there occur the remains of two very remarkable ganoidal fishes. They deserve our attention for their great size, their complex organization, and the important place in the scale of animal life which they occupied during a former period. One of them has been called *megalichthys* or *great fish*—an unhappy name, since the animal did not reach the dimensions attained by not a few of the other ganoids, and was even surpassed by at least one of its contemporary congeners. The other is known as the *holoptychius* or *wrinkled scale.* A more detailed examination of these two animals will perhaps best enable us to understand the character of the ganoid fishes that lived in the waters of the Carboniferous period.

The megalichthys had an average length of about three feet. Like the other members of the ganoid order it had a glittering exterior, every scale and plate being formed of strong bone, and coated with a bright layer of enamel. Wherever this polished surface extends, it is found to be ornamented with a minute punctulation, the pores of which lie thickly together like the finer dots of a stippled engraving. The cranial plates are further varied by a scattered and irregular series of larger punctures that look as if they had been formed by the insertion of a pin-point into a soft yielding surface. The examination of the head of the megalichthys as depicted in Fig. 30, will convey an adequate conception of the structure of a ganoidal cranium.

The snout is formed of an elegantly curved bone (*c*) fringed along its under edge with minute thick-set teeth. On either side it is flanked by two triangular plates, which occupy the space between the intermaxillary bone (*c*) and the upper jaws (*q q*). The eye orbits seem to have been at the corners of the intermaxillary, circumscribed by the sub-orbitals (*f g h*) and the ethmoids (*b*). The massive intermaxillary bone had its posterior margin of an angular form, and into the notch thus formed there was wedged the anterior end of a long strip of plates, which expanded as they approached the occipital part of the cranium,

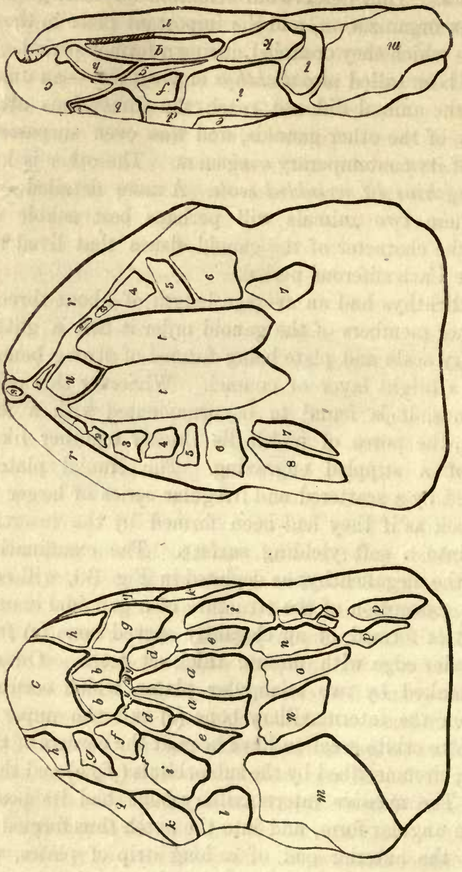


FIG. 30.—Head of Megalichthys Hibberti, one-sixth of nat. size (Agass. *Poiss. Foss.* Tab. 63). A Upper side. B Under side. C Profile.

and terminated in three irregular plates that may represent the place of the parietal and occipital bones. The space between this belt and the upper jaws was occupied by three large plates (i k l) which in other ganoids, as the *osteolepis* of the Old Red Sandstone, were united into a single pre-opercular bone of considerable size. The operculum or gill cover (m) was relatively large, and had an elegantly curved anterior margin. The upper jaws (q) were comparatively small, and had a fringe of small conical teeth. The under jaws (r r) reached to nearly double the length of the upper, and were similarly set round with teeth. The teeth of the megalichthys, like those of the living lepidosteus, consisted of two kinds, of which the one bristled thickly along the outer edge of the jaw as sharp minute points, averaging about a line in length, while behind this outer row lay a scattered series of much larger teeth that sometimes rose nearly an inch above the jaw. The external surface of these more formidable tusks is smooth, glittering, and minutely striated with fine lines from base to point, while the root of each is farther marked by a circle of short, deep, longitudinal furrows. The internal structure displays a close ivory, which when viewed under a microscope is seen to be made up of fine tubes radiating from the outer surface to the hollow central cavity. Some of the bones in the interior of the mouth seem to have been also furnished with an apparatus of teeth. The under surface of the cranium between the arch of the under jaws consists of two oblong central plates (t) surrounded by a row of sixteen irregular ones, eight on each side, and terminated in front by a large lozenge-shaped scale (u) which fits into their angle of junction on the one side, and into the symphysis of the jaws on the other. In the osteolepis there were likewise two large plates terminating in a similar lozenge-shaped one, but without the flanking rows. In the famous Old Red holoptychius of Clashbennie, the under surface of the head had but two plates, and in the still older and more gigantic asterolepis, there was

but one. It is the delightful task of the palæontologist to compare and contrast these various pieces of mechanism, to mark how what seems lacking in one comes to be supplied in another, and to trace out the various modes in which, during the ages of the past, Nature has wrought out the same leading plan, sounding, as it were, an ever-changing series of modulations upon one key-note. In comparing together the ganoids of the Old Red Sandstone and the Carboniferous rocks, he finds that in the asterolepis—a fish belonging to the lower part of the former formation—the pointed arch formed by the sweep of the lower jaws is filled up by a single plate like some abbey-window with its mullions knocked away, and built up with rude stone and lime. Higher in the same group of rocks he meets with the cranium of the holoptychius, where there is one straight central mullion running in an unbroken line from the angle of the arch to its base. In the osteolepis [1] he sees this mullion branching into two at its upper end, so that the window consists of three divisions, as in the simplest style of Gothic. Passing upwards into the Carboniferous system, he encounters a still more ornate arrangement in the cranium of the megalichthys. The central mullion with its two upper branches still remains, but it is flanked by an additional one on each side, from which there spring six cross bars that diverge obliquely with a slight curve, so as to join the outer arch and subdivide the window into nineteen compartments. So varied are the plans of the Divine Architect in what to man may seem such a little matter as the piecing together of a fish's skull.

The body of the megalichthys was cased in an armature of as solid and glittering bone as that which defended its head. Where the plates of the cranium ended off they were succeeded by large rhomboidal scales that crossed the body obliquely, and overlapped each other like the metal plates in the antique scale-

[1] Hugh Miller's *Footprints of the Creator*, p. 91.

armour. Each scale consisted of two parts, of which one had a rhomboid form and was covered over with enamel, while the other ran round the two inner sides of the rhomb as a broad unenamelled selvage deeply indented along its centre. It was the enamelled portion alone that formed the outer surface, the rough unpolished border being covered by the overlapping edges of the adjoining scales. The scales had not a uniform thickness, but were strongest at the covered part from which each thinned off to the outer edges. In this way the thin edge of one scale pressed down on the thick part of the subjacent one, and a covering of uniform strength and smoothness was produced. Looking at a set of these scales as they still occupy their original position on the creature's body, it is scarcely more than a half of each which meets our eye ; for the unenamelled border occupied about a third of the entire surface, and a fourth of the remainder was covered by the overlapping scales. The effect of this arrangement must have been to combine great strength with the most perfect flexibility. Notwithstanding the bulk of his helmet and the weight of his scale-armour, we cannot conceive the megalichthys to have been other than a lithe, active, predaceous fish, dealing death and destruction among the herring-like shoals of little palæonisci and amblypteri, though able to maintain perhaps but a doubtful warfare with his more bulky contemporary, the holoptychius. The internal structure of the scales of the megalichthys exhibits the same provision for combining strength with the least possible amount of material. Viewed in a transverse section under a magnifying power of about eight diameters, they are seen to consist of three layers of bone, each possessing a peculiar structure. The outermost is formed of a tessellated pavement of minute round ocelli, having a fine brown colour, and placed close together with considerable regularity. They somewhat resemble little wheels, the axle being either a dark solid nucleus or a small circular aperture, whence there radiates to the outer rim a set of exceedingly minute fibres

which were originally hollow, and served as canals to carry on the growth of the scale. The vacant space left where four wheels impinge on each other, forms one of the pores that cover the enamelled surface of the scale. The whole structure of this outer layer very closely resembles that presented by the internal part of the base of the teeth, save that the confluent lobes shown in the teeth become in the scale detached into separate and independent circles. The central stratum of each scale is composed of a loose open network of cancellated bone that passes into the layer on either side, and resembles in its general texture the osseous vertebræ of the same fish. The under layer, one end of which rested immediately on the skin, approaches more to the firmness and solidity of the outer one, but, in place of a tessellated, ivory-like pavement, it had a close fibrous texture, with here and there a scattered cavity, and the fibres were matted together so as to resemble the more solid structure of the cranial bones. The effect of this triple arrangement must have been to impart great strength and lightness to the external armature of the fish ; the middle spongy layer serving, by its porosity, at once to deaden the effect of any blow aimed at the outside, and to give bouyancy and lightness to what would otherwise have been a coat of mail well-nigh as ponderous as that of a feudal chief. One can hardly conceive any implement of warfare in use among the lower animals of strength enough to pierce this massive covering. But we shall find as we go on that if the megalichthys had a strong defensive armour, a bulkier neighbour had a still stronger offensive one, and that the enamelled plates of the one fish were scarcely a match for the huge pointed tusks of the other.

The megalichthys had an osseous skeleton, with vertebræ of a discoidal form. These internal bones when viewed under the microscope are found to display an open cancellated structure, resembling that of the central layer in the scales. It thus appears that this ancient fish was not merely defended by a

hard external armour, but possessed an equally solid framework of bone within.

Mingled with the scales and bones of the megalichthys, there are found the remains of a still larger fish, to which the name of Holoptychius has been given. Its external ornament differed entirely from that of the animal last described. It possessed teeth sometimes six or seven times larger, and jaws, plates, and bones of a form and dimensions totally distinct. Strange as it may seem, however, these two fishes have been constantly and systematically confounded from the time when they were first discovered. Two or three years ago, there might be seen in the British Museum several specimens of the holoptychius, of which some bore the correct name, while the rest were labelled "Megalichthys;" and a similar error prevailed in several of the other museums.[1] The confusion can be traced very distinctly in the memoir of Dr. Hibbert, who for the first time described the remains of these fishes, and wrote according to information received from Agassiz.

In the autumn of 1832, the attention of the scientific public of Edinburgh was directed to the extraordinary character of some fossil remains obtained from the lime-quarries of Burdiehouse, a village about four miles to the south of the town. Dr. Hibbert visited the locality, and soon saw enough to excite his lively interest in its thorough investigation. The Royal Society of Edinburgh warmly supported his exertions, and by their means a large suite of specimens was eventually obtained, which the Doctor from time to time described as they were successively received. At the meeting[2] of the British Association in Edinburgh, in 1834, the specimens were exhibited before the Geological Section, and a memoir upon them read by their successful discoverer. On the conclusion of the paper, a lively

[1] The mistake was noticed in 1845 by Hugh Miller, who, in a foot-note to his *First Impressions of England and its People*, p. 71, well defines the distinctions between the two ichthyolites.

[2] See Agassiz, *Poiss. Foss.*, tom. ii. Part 2, p. 89 *et seq.*

discussion ensued upon the nature of the animal to which the scales and teeth had belonged. Dr. Hibbert argued, from the deeply-furrowed teeth, and the strong, massive cranial plates, that the animal must have been a reptile, and supported his assertion by no small amount of anatomical skill. In the midst of the discussion, a message was sent to the great ichthyologist of Neufchatel, who happened to be at that time busily engaged in the Zoological Section. Passing over the fossils as they lay grouped upon the table, with that quick perception for which he is so justly celebrated, Agassiz at once decided that the bones must have been those of some large and hitherto undescribed *fish*. Such a decision from such an authority produced of course no little sensation, and the naturalist was told with some surprise that the remains had just been elaborately described as those of extinct reptiles. "Reptiles!" thought Agassiz, and again his quick eye darted over the table; but the fossils would yield no other answer than what they had already given. Despite their seeming reptilian character, they were undoubtedly ichthyic, though belonging to an animal up to that time unknown. In the completed memoir which Dr. Hibbert subsequently submitted to the Royal Society, his mistake was freely acknowledged, and the remains there flourish as those of a true fish. But with this amendment a grave error of another kind was committed, though in this the Doctor seems to have been supported by the authority of Agassiz himself. The large bones, scales, and teeth of the Burdiehouse limestone, were all indiscriminately thrown into one genus, to which Agassiz gave the name of Megalichthys; and in the memoir we find the different kinds of scales and teeth described and figured without the slightest intimation or suspicion that they might possibly have belonged to different animals. The novelty of the discoveries soon attracted general attention to Dr. Hibbert's paper. It was quoted or referred to in almost every scientific work treating of general geology, while in some instances (as in Dr.

Buckland's *Bridgewater Treatise*) the erroneously-named bones were re-engraved. A tooth from the Fife coal-field, drawn for one of the woodcuts in a popular elementary manual, was also named megalichthys; an error perpetuated through every edition till the last, where the tooth has been restored to its true owner—the holoptychius. In truth, no two organisms have ever been so maltreated; and if the reader will kindly bear with me a little further, it will not be difficult to show him that the holoptychius had peculiarities of its own quite as distinct as those that have come before us in the megalichthys, and that each animal has a full and legitimate claim to a separate and independent niche in the gallery of fossil fishes.

The word *holoptychius* means, as I have said, "wrinkled or folded all over,"—a name truly expressive of the peculiar style of ornament displayed by every part of the exterior of the animal's body. The head-plates, which are of great size, exhibit a fine corrugated shagreen-like surface, roughened into knobs, and wavy lines of confluent tubercules, that remind one disposed to be fanciful, of a frosty December moon with its isolated peaks and confluent mountain chains. The scales are of a rounded or oval form, and vary from less than half an inch to fully four or even five inches in diameter. Their upper side consists of two parts, one of which with a crescent shape lay beneath the overlapping scales, while the other passed outwards to form a portion of the outer visible surface. The part that was hidden by the overlapping scale was smooth, with a finely striated surface. The exposed portion displayed the usual corrugated sculpturing, many of the little tubercules having striated sides, and showing, in consequence, no little resemblance to the star-like knobs on the dermal covering of the Old Red Sandstone asterolepis. The inner surface of the scales was concave, with a central prominent oblong point surrounded by encircling scaly ridges, and forming what is called the centre of ossification.[1]

[1] The above descriptions of the scales and teeth of these two fishes, are taken from

But perhaps the most remarkable and characteristic parts of the carboniferous holoptychius were its jaws and teeth. As we might readily conjecture from the great size and strength of the scales and cranial plates of this fish, its dentition was of a correspondingly massive type. The under jaw, with the usual corrugated ornament, frequently exceeded a foot in length, and displayed along its upper edge a thick-set group of teeth. Of these there were two kinds—one of a smaller size and more blunted form, with short indented furrows at their base; the other of a greatly more formidable size, grouped at intervals among the smaller ones. The front end of each under jaw bore one of these long conical tusks, serving as it were to guard the entrance of the mouth. Each of the larger teeth had a base strongly marked with longitudinal furrows, and sank deep into the jaw, with the bone of which it sometimes anchylosed.[1] The part of the tooth above this socket had an oval form, so flattened as to present two cutting edges, one facing the front, the other the back of the mouth, and meeting at the upper end of the tooth which was sharp and pointed. Such large conical tusks may frequently be obtained, having a length of two or

specimens in my own collection. None of my holoptychian scales show incontestably the proportion of the covered to the exposed part. Judging from the aspect of one of them, the wrinkled portion occupied perhaps about three-fifths of the entire scale, the remaining part being covered by the overlapping edges of those adjacent; for the characteristic corrugated surface was essentially an external ornament, and ceased at the point where the external bone passed into the interior. I may remark, that the upper side of the scales is not very frequently seen in the Burdiehouse limestone, the rough surface usually adhering to the rock, and leaving only the smooth inner side exposed. Out of seven specimens from that locality, only one shows the upper side, and that by no means in a perfect state of keeping. The structure alike of scales and bones can be seen to much greater advantage in the shales, ironstones, and coals of the coal-fields, where, owing to the soft nature of their matrix, the fossils can be readily cleared and exposed.

[1] I have seen detached teeth, wherein the length of the root, or part imbedded in the jaw, tripled that of the exposed part, sinking four or five inches into the bone without any trace of anchylosis. Whether these huge tusks belonged to the upper or under maxillary, I do not pretend to say, though no specimen of the under jaw, which has ever come under my notice, would accommodate half of such a deep-sunk base.

three inches, while occasionally they range as high as six or seven, the smaller teeth seldom reaching so much as an inch.

FIG. 31.—Jaw of Holoptychius (*Rhizodus.*—Owen) from Gilmerton, one-fourth nat. size; the large teeth along the middle part of the jaw are here wanting.

It is difficult to see how, with such a formidable dentition, the jaws could readily close. In some specimens I have seen deep hollows beside the bases of the teeth, which may possibly have received those of the opposite jaw, but the gigantic tusks at the entrance of the mouth seem to have stood high over the jaw, passing outside like those of the wild-boar. If this be correct, the jaw of the holoptychius would unite the mechanism of both the alligator and the crocodile—its recipient hollows being analogous to the tooth-pits in the former tribe, and its protruded teeth to the similarly exposed teeth of the latter.

When we bring the microscope to bear upon the elucidation of the structure of these ancient teeth, it seems as if our labour had but just begun; and that so far from having by an external scrutiny exhausted all that they have to show us, our knowledge of them can be but scanty and superficial until we have studied them carefully under a magnifying power. Microscopic sections of such organic remains are prepared in the same way as those of the fossil woods already noticed; and a more interesting or beautiful series of objects cannot be conceived than a set of slices of these fossil-teeth.

Viewed, then, in longitudinal section from base to point, the part above the fluted root of one of the large teeth of the holo-

ptychius is seen to consist of minute hair-like fibres of extreme tenuity, which proceed in straight lines from the outer surface to the interior. At right angles to these, and parallel with the outer edges, there is a set of dark widely-placed lines conforming to the outline of the tooth, like so many long sugar-loaf shaped caps, placed within each other. When this part is cut across, and viewed in transverse section, the tooth is observed to be of a flattened oval form, with the same fine fibres or tubes radiating from the centre, and traversed by the same dark bands which now assume the form of concentric rings. The appearance thus presented reminds one at once of a cross section of some dicotyledonous tree, the dark bands resembling the annual layers of growth, and like these resulting from a similar thickening of the internal tissue. The upper part of the tooth is solid and the concentric rings few; the middle exhibits an increase of the rings, and possesses, moreover, a hollow centre or pulp-cavity,[1] with the usual diverging fibres. Here the oval form is well shown, and the encircling rings are considerably flattened at the ends of the long axis.

The lower portion of the tooth exhibits a much more complicated texture. Externally it is marked by deep longitudinal furrows, that run down the enamelled sides and sink into the jaw. When cut across at this ribbed part, the tooth is found to present the most complex and graceful internal structure. The prominent ridges between the furrows are seen to be produced by crumpled folds of the substance of the tooth, which roll inwards towards the centre, coalescing with each other, and forming intricate groups of circling knots and folds. In some places they seem all but separated from each other into little circles, pierced with a central aperture, and recall the aspect of the upper layer in the scale of megalichthys. Each of these loops and folds presents a texture exactly similar to that of the

[1] This hollow centre may be seen occasionally filled up by a sharp conical tooth like the *phragmocone* of a belemnite.

upper part of the tooth. The same minute hair-like tubes, darkened and thickened in the long axis, radiate towards the centre; the same concentric bands run from centre to circumference; so that the lower part of the tooth seems, as it were, made up of a bundle of smaller teeth partially melted into each other. Between these loops and folds circular meshes frequently occur, and add to the complexity as well as the beauty of the whole structure. One of these sections, with all its twisting crumples, and folds, and knots, and coloured meshes, and encircled rings, bears no small resemblance to an antique polished table that has been cut out of the gnarled roots of a venerable oak. This complex structure arose from the mode of growth of the tooth; each prominent external ridge continually turning inwards down the furrow on either side, and mingling in freakish knots with the folds that had gone before.[1]

The internal bones of the holoptychius were of great size and strength, as befitted such a bulky ganoid. Some of them had a singular style of surface ornament, that somewhat resembled a frosted widow on a December morning. Their internal structure was loose and cancellated; the endo- being usually of a less compact texture than the exo-skeleton. Judging from the size of such bones, the carboniferous holoptychius must have been one of the bulkiest and most formidable denizens of the deep, reaching sometimes to a length of twenty feet or even more. Such an animal would have been, perhaps, quite a match for our hugest crocodile or alligator, for it must have swum about with a litheness and agility possessed by none of the saurian reptiles. Like that leviathan chosen by the Almighty, in an age long subsequent, as an illustration of His power and greatness, the holoptychius must have been king over all the inhabitants of

[1] For an acquaintance with the remarkable teeth of this ancient fish, more minute than it had been my good fortune to possess before, I am indebted to a most interesting series of microscopical preparations kindly lent me from his extensive collection by my friend Mr. Alexander Bryson of Edinburgh.

the sea, and the magnificent language of Job, descriptive of the living animal, applies not less graphically to the extinct one :—
"Who can open the doors of his face? his teeth are terrible round about. His scales are his pride, shut up together as with a close seal. One is so near to another, that no air can come between them. He maketh the deep to boil like a pot: he maketh the sea like a pot of ointment. He maketh a path to shine after him; one would think the deep to be hoary."

Our survey has hitherto been directed to the denizens of carboniferous lake, river, and sea, and we have found them to be alike important in numbers and interesting in organization. It is otherwise, however, when we turn in search of the denizens of the carboniferous lands. The crowded trees and shrubs of the coal strata recalling as they do old forest-covered swamps, might seem to indicate the probability of a pretty numerous terrestrial fauna. Where are we to look for the fossilized relics of land animals, if not in the remains of a submerged land-surface? And yet, strange as it may seem, of the inhabitants of the land during the Coal-measure period we know almost nothing. "We have ransacked hundreds of soils replete with the fossil roots of trees,—have dug out hundreds of erect trunks and stumps, which stood in the position in which they grew,—have broken up myriads of cubic feet of fuel, still retaining its vegetable structure,—and, after all, we continue almost as much in the dark regarding the invertebrate air-breathers of this epoch, as if the coal had been thrown down in mid-ocean."[1]

The little land-shell already noticed as having been detected by Sir Charles Lyell in the carboniferous rocks of Nova Scotia, seems to be as yet the only air-breathing mollusc obtained from rocks of such high antiquity. Insect remains have been detected in the English coal-fields belonging to two or three species of beetles; while on the Continent, wing-sheaths and other fragments of cockroaches, scorpions, grasshoppers, locusts, crickets,

[1] Sir Charles Lyell's *Elements*, fifth edition, p. 406.

&c., have been detected. But the most remarkable traces of air-breathers consist in various indications of the existence of reptiles during the Carboniferous era. Fragmentary skeletons, with detached bones and plates, have been found in Bavaria and America, together with long tracks of footprints, from which it appears that during the time our coal-seams were forming, there swam through the sluggish deltas, or crept amid the dank luxuriant foliage, strange lizard-like forms, large enough to leave behind them on the soft yielding mud or sand the impress of their double pair of toed feet. But of these animals we have much to learn. Some of them have bequeathed to us merely their dismembered broken bones ; others have left but the imprints of their toes. Yet even these remains, trifling as they may seem, become of importance when we remember that they demonstrate fishes not to have been the highest types of being during the epoch of the Coal, and show that while the bulky holoptychius held the supremacy of the waters, lizard-like forms of a less formidable type seem, so far as we know, to have ruled it over the land.

In fine, then, no one can glance at a list of the carboniferous fauna without perceiving either that the animated world of that ancient epoch must have had a very different proportioning from what now obtains, or that we have only a meagre and fragmentary record of it. That the latter conclusion is the more philosophical will appear if we reflect upon the many chances that exist against the entombment and preservation of animal remains, especially of those peculiar to the land. How very small a proportion of the remains of animals living in our own country could be gathered from the surface-soil of any given locality, and how very inadequate would be the meagre list of species thus obtained, as representing the varied and extensive fauna of Great Britain ! In contrasting, then, the rich abundance of marine organisms with the extreme paucity of terrestrial animals among the carboniferous rocks, it would be too

hasty to infer a corresponding disproportion originally. It must be admitted that the rarity of air-breathers, after such long-continued and extensive explorations among terrestrial and lacustrine beds, presents a difficult problem, only (if at all) to be cleared away by patient and persevering investigation. With this preliminary caution, we may regard the carboniferous fauna as peculiarly rich in marine species. The sea-bottoms swarmed with stone-lilies, cup-corals, and net-like bryozoa, mingled with the various tribes of molluscan life—the brachiopods with their long ciliated arms; the bivalves and gastropods with their coloured shells that recall some of the most familiar objects of our shores; and the cephalopods with their groups of siphonated chambers, straight as in the orthoceras, or gracefully coiled as in the goniatite. The seas swarmed, too, with fishes belonging to the two great orders of ganoids and placoids, the latter represented now by our sharks and rays, though the exact type of the ancient genera is retained only by the cestracion or Port-Jackson shark; the ganoids, with their strong armour of bone, represented by but two genera, the lepidosteus of the American rivers, and the polypterus of the Nile,—two fishes that seem but as dwarfs when placed side by side with the gigantic holoptychius of the coal-measures. The rivers and estuaries of the same period seem to have been frequented by immense shoals of the smaller ganoidal fishes that fed on decaying matter brought down from the land, and perhaps, too, on the minute crustacea that lay strewed by myriads along the bottom. Into these busy scenes the bulkier monsters from the sea made frequent migrations, perhaps in some cases ascending the rivers for leagues to spawn, and returning again to their places at the mouth of the estuary or in open sea. The rivers and lakes swarmed with small crustaceous animals, and nourished, too, shells like those of our pearl-mussels. The land—so luxuriantly clothed with vegetable forms—was hummed over by beetles, chirupped over by grasshoppers and crickets, and crawled

over by four-footed reptiles, that united in their structure the lizard and the frog. But of the general grade and proportions of its denizens we still remain in ignorance. From all that yet appears, the scenery of these forests must have been dark, silent, and gloomy, buried in a solitude that was startled by no tiger's roar, no cattle's low, and neither cheered with the melody of birds nor gladdened by the presence of man.

We have lingered, perhaps, too long over the remains of these old carboniferous animals. But the delay may be not without its use if, by thus bringing before us some of the more marked points in the structure of creatures that for ages peopled our planet, it broaden our view of creation; and by lifting the curtain from off a dim, distant period of our world's long history, it show, amid all diversities of arrangement, and all varieties of form, still the same grand principles of design, and the same modes of working as those which we can see and compare among the living forms around us. It is something to be assured that the race of man has been preceded by many other races, lower indeed in the scale of being, but manifesting, throughout the long centuries of their existence, ideas of mechanism and contrivance still familiar to us, and serving in this way to link the human era with those that have gone before, as parts of one grand scheme carried on by one great Creator.

CHAPTER VIII.

Sand and gravel of the boulder—What they suggested—Their consideration leads us among the more mechanical operations of Nature—An endless succession of mutations in the economy of the universe—Exhibited in plants—In animals—In the action of winds and oceanic currents—Beautifully shown by the ceaseless passage of water from land to sea, and sea to land—This interchange not an isolated phenomenon—How aided in its effects by a universal process of decay going on where-ever a land surface is exposed to the air—Complex mode of Nature's operations—Interlacing of different causes in the production of an apparently single and simple effect—Decay of rocks—Chemical changes—Underground and surface decomposition—Carbonated springs—The Spar Cave—Action of rain-water—Decay of granite—Scene in Skye—Trap-dykes—Weathered cliffs of sandstone—Of conglomerate—Of shale—Of limestone—Caverns of Raasay—Incident—Causes of this waste of calcareous rocks—Tombstones.

From the blackened plants that darkened the upper layers of the boulder, the transition was natural to the matrix in which they lay. The whole rock consisted of a fine quartzy sand more or less distinctly laminated, and showing in its lower parts well-rounded pebbles of quartz, green grit, and felspathic trap. The contemplation of these features suggested the existence of some old land with elevated ranges of hills, and wide verdant valleys traversed by rivulets and rivers which bore a ceaseless burden of mud, sand, and gravel, onwards to the sea. The pebbles afforded some indication of the kind of rocks that formed the hill-sides. Perhaps the higher grounds exhibited that grey wrinkled appearance peculiar to the quartz districts of the north-western Highlands, with here and there a bluff crag of felspathic trap shooting up from among the fern-brakes of the valley, or cutting across the channel of some mountain stream that tumbled over the pale rock in a sheet of foam.

And there may have been among these uplands smooth undulating districts, dotted over with dark araucarian pines, and densely clothed with a brushwood of rolling fern, but which showed in all their ravines the green grit that formed the framework of the country,—its beds twisted and contorted, jointed and cleaved, like the grits and slates along the banks of many a stream, beloved by the angler, in the classic ground of the Ettrick and the Yarrow. But whatever may have been the special features of its scenery, there can be no doubt of the land's existence. The carbonized plants stand up to tell us of its strange and luxuriant vegetation. We have listened to their story, and suffered them to lead us away into forest, and and lake, and sea, to look on the various forms of life, vegetable and animal, which abounded in that far-distant age. We return again to the boulder, and shall now seek to learn the lessons which the sand and pebbles have to teach us. Their subject belongs to what is called physical geology, and will bring before us some of the more mechanical operations of nature, such as the slow but constant action of air, rain, and rivers, upon hard rock, the grinding action of the waves, and the consequent accumulation of new masses of sedimentary rock.

In all the departments of nature that come under the cognizance of man, there is seen to be an endless succession of mutations. According to the Samian philosopher—

> "Turn wheresoe'er we may by land or sea,
> There's nought around us that doth cease to be.
> Each object varies but in form and hue,
> Its parts exchange; hence combinations new.
> And thus is Nature through her mighty frame
> For ever varying, and yet still the same."

In the world of life we see how animals are sustained by a constant series of chemical changes in their blood, every respiration of air adding, as it were, fresh fuel to the flame of life within. In plants, too, there is an analogous process. The

atmospheric air is by them decomposed, part of it being given off again, and part retained to build up the organic structure. Plants withdraw mineral matter from the soil, animals feed upon plants, and thus the earthy substances, after having formed a part, first of rock masses, then of vegetable, and subsequently of animal organizations, are returned again to the soil, whence to be once more withdrawn and undergo new cycles of mutation. But this perpetual interchange is not confined to the vital world. We see it in the action of winds, when heated air rises and moves in one direction, and the colder parts sink and travel the opposite way. The same principle is exhibited by the oceanic currents, the removal of a body of water, from whatever cause, always necessitating the ingress of a corresponding quantity to supply its place. But perhaps one of the most beautiful instances of these interchanges in the whole inorganic world is the ceaseless passage of water from the land to the sea, and from the sea to the land. The countless thousands of rivulets, and streams, and gigantic rivers, that are ever pouring their waters into the great deep, do not in the least raise its level or diminish its saltness. And why? Simply because the sea gives off by evaporation as much water as it receives from rain and rivers. The vapour thus exhaled ascends to the upper regions of the atmosphere, where it forms clouds, and whence it eventually descends as rain. The larger part of the rain probably falls upon the ocean, but a considerable amount is nevertheless driven by winds across the land. This finds its way into the streams, and so back again to the sea, only, however, to be anew evaporated and sent as drizzling rain across the face of land and sea. This interchange is constantly in progress, and seems to have been as unvarying during past ages.

But the ceaseless passage of water between land and sea is not a mere isolated and independent phenomenon. Like all the rest of Nature's processes, even the simplest, it produces

important and complicated effects. And the reader may, perhaps, think it worth looking at for a little, when he reflects that to this seemingly feeble cause we owe no small part of our solid lands, whether as islands wasted by the sea, or as part of vast and variegated continents, wide rolling prairies covered with verdure and roamed over by herds of cattle, or wintry Alpine hills lifeless and bare.

The truth of this will appear when we reflect that the moisture which rises from the sea and falls on the land as rain, is free from any admixture of impurities; but by the time it again reaches the sea, after a circuit of perhaps many miles down valley and plain, it has grown turbid and discoloured, carrying with it a quantity of mud, sand, and drift-wood. The sediment thus transported soon sinks to the bottom, where it eventually hardens into rock, and in course of time is raised above the waves as part of a new land. Such I conceive to have been the origin of the sand, gravel, and imbedded plants of our boulder. It may be well, however, in going into the details of the subject, to take a wider view of this interesting branch of geology, and look for a little at the forms and modes of the decomposition of rocks, and the varied manner in which new sedimentary accumulations are formed.

All over the world, wherever a land surface spreads out beneath the sky, there goes on a process of degradation and decay. Hills are insensibly crumbling into the valleys, valleys are silently eroded, and crags that ever since the birth of man have been the landmarks of the race, are yet slowly but surely melting away. It matters not where the hill or plain may lie, the highest mountains of the tropics and the frozen soil of the poles, yield each in its measure and degree to the influence of the general law. It might seem that so universal a process should be the result of some equally prevalent and simple cause. But when we set ourselves to examine the matter, we find it far otherwise. The waste of the solid lands, in place of arising

from some single general action, is found to result from a multiform chain of causes, often local in their operation and variable in their effects. Such an investigation affords a good illustration of the general mode and fashion in which Nature delights to work. It shows us that what may seem a very simple process may be in reality a very complicated one ; that in truth there exist in the world around us few if any simple, single processes, which stand out by themselves unconnected with any other ; that, on the contrary, all become intimately linked together, the effects of one often forming part of the chain of causes in another, and producing by their combined action that complex yet strikingly harmonious order that pervades all the operations of Nature. To an extent of which Cicero never dreamed, there runs through all the world " such an admirable succession of things that each seems entwined with the other, and all are thus intimately linked and bound together." [1] Man separates out these various processes, classifies and arranges them, because from the imperfection of his mental powers he cannot otherwise understand their effects ; all would seem but chaos and confusion. But the formal precision and the sharp lines of demarcation exist only in his mind. They have no place in the outer world. There we see process dove-

[1] Cicero, *De Nat. Deor.* lib. i. 4. So, in Bacon's *Wisdom of the Ancients*, under the fable "Pan or Nature :"—"The chain of natural causes links together the rise, duration, and corruption ; the exaltation, degeneration, and workings ; the processes, the effects, and changes, of all that can any way happen to things." Such is the philosopher's explanation of the Destinies as sisters of Pan. In no part of his writings can the thorough practical character of Bacon's philosophy be more conspicuously seen than in his treatment of these ancient fables. Glancing over the titles of the different papers, you are tempted to wonder what an intellect which could only appreciate poetry as a mode of narrating history or as a vehicle for the teaching of truth, will make of such fairy tales as those of Pan, Orpheus, Proteus, Cupid, and many others. They seem like so many airy Naiads crushed within the iron grasp of a hundred-handed Briareus. But a perusal of those delightful pages will show that the giant has really no malevolent intentions towards his fair prisoners ; nay, that he only wishes, by stripping them of their paint and finery, to show that, with all their lightness and grace, they are nevertheless strong buxom dames, of the same doughty race with himself.

tailing with process, and spreading out over the material world in an endless network of cause and effect. We feebly try to trace out these interlacing threads, but we can follow them far in no direction. Proteus-like, they seem to change their aspect, blending now into one form, now into another, and so eluding our keenest pursuit.

As an instance, therefore, of this remarkable interlacing of different causes in what we call a single process, the disintegration of rocks deserves our attention. In ordinary language, we say a stone rots away, and its debris is washed down by the rains and streamlets, and the process does not at first sight seem at all more complex than the expression used to describe it ; yet if we examine the subject, we shall ere long find that there are in nature many simpler things than the rotting away of a stone. To effect such a result, there come into play a whole category of agencies, chemical and mechanical, so combined in their operation, and so intimately blended in their effects, that it becomes no easy task to tell where one set ends and another begins.

A rock is said to undergo a chemical change, when one or more of its component parts passes from one state of combination to another—as, for instance, when a mineral absorbs oxygen, and, from the condition of a protoxide, changes into that of a peroxide ; or when, parting with its silicic acid, it takes an equivalent amount of carbonic acid, and in place of a silicate becomes a carbonate. Now these, and similar metamorphisms, are chiefly produced by water permeating through the rocky mass, and thus no sooner does the old combination cease, than the new one which replaces it is dissolved by the slowly filtering water, and carried away either to greater depths, or to the surface. Every drop of water, therefore, that finds its way through the rock, carries away an infinitesimal portion of the mineral matter, and the stone is consequently undergoing a continual decay. This condition of things may go on either at

some depth in the earth's crust, or on the surface. In the former case, springs and percolating water are the agents in effecting the change ; in the latter, it is produced chiefly by rain and streams. But wherever the process goes on, the results, unless where counteracted by some opposite agency, are ultimately the same. It may be of use to look at some examples of these changes, and, by dividing them in a rough way, into underground and surface actions, we shall be enabled to mark more clearly their effects.

A common source of the decay of rocks arises from the percolation through them of water charged with carbonic acid. Decomposing vegetation gives off a large amount of this gas, which is readily absorbed by rain-water. The water sinks into the ground filtering through cracks and fissures in the rocks, whence it afterwards re-emerges in the form of springs. Now wherever, in its passage through these subterranean rocks, the water meets with any carbonate, the carbonic acid contained in the liquid immediately begins to dissolve out the mineral matter, and carries it eventually to the surface. There the amount of evaporation is often sufficient to cause a re-deposit of the mineral in solution. If it be lime, a white crust gathers along the sides of the stream, delicately enveloping grass-stalks, leaves, twigs, snail-shells, and other objects, which it may meet with in its progress. Such "petrifying" springs, as they are popularly termed, occur abundantly in our limestone districts. It should be borne in mind, however, that they only produce an incrustation round the organic nucleus, and do not petrify it. That alone is a true petrifaction where the substance is literally fossilized, or turned into stone. A familiar instance of a similar chemical process may be seen under many a bridge, and along the vaulted roofs of many an old castle. Numerous tapering stalactites hang down from between the joints of the masonry, resembling, so to speak, icicles of stone, often of a dazzling whiteness. They are formed by the percolation of carbonated

water through the mortar of the joints, the carbonate of lime thus withdrawn being re-deposited where the water reaches the air and evaporates. A little pellicle of lime first gathers on the roof, and every succeeding drop adds to the length of the column. In some cases, where the supply of water is too great for the amount of evaporation, part falls on the floor, and, being there dissipated, leaves behind a slowly-gathering pile of lime called stalagmite. In some of the Eastern grottos, the pillars from the roof have become united to those on the floor, forming the most exquisite and fairy-like combinations of arch and pillar. An example of a calcareous grotto has now become pretty familiar to our summer tourists, under the name of the Spar Cave. It lies on an exposed cliff-line along the western shores of Skye, against which the surge of the Atlantic is ever breaking. You approach it from the sea, and enter a narrow recess between two precipitous walls of rock, open above to the sky, and washed below by the gurgling tide. Crossing the narrow, shingly beach, you find the ground thickly covered with herbage, while, grouped along the dark walls, are large bunches of spleenwort, hart's-tongue fern, and other plants that love the shade. Soon after entering the cave, all becomes sombre and cold; and the few candles, with which the party have furnished themselves, only serve to heighten the gloom. After scrambling on for a time across dank, dripping rocks, and over a high bank of smooth marble, on which it is difficult to creep, almost impossible to stand, you arrive at a deep pool of clear, limpid water, which extends across the cave from side to side, barring all farther passage. The scenery at this point will not readily be forgotten. The roof towers so high that the lights are too feeble to show it, while the walls, roughened into every form of cusp and pinnacle, pillar and cornice, all glittering in the light, resemble the grotto of some fairy dream. On returning again to the light of day, if you ask the cause that has given rise to all this beauty, it will be found a very simple one.

The cleft occupied by the cave has been once filled by a wall of igneous rock called a trap-dyke. Atmospheric influences, aided probably by the waves, have caused the decomposition and removal of this intruded rock, and the calcareous sandstone on either side now stands up in a wall-like form. The upper part of the dyke remains as a roof to the cave, but it has become completely covered over with the calcareous deposits left by the carbonated water that filters through the adjacent limy sandstone. The amount of water is considerable, and consequently every part of the cavern—roof, walls, and floor—has been incrusted with a white crystalline carbonate of lime. In volcanic countries, where the springs often come to the surface in a highly heated state, charged, too, with various chemical ingredients, they produce no slight amount of physical change on the surrounding districts, and must be regarded as important geological agents.

But perhaps the most common and widely-diffused form of decomposition, is that produced on the surface of the earth by the action of rain-water, in slowly dissolving out the soluble parts of rocks, and washing away the loose, incoherent grains that remain behind. It is hard to say whether this process is more chemical or mechanical. The solution of the mineral matter belongs to the former class of changes, while the removal of debris must be ranked among the latter. The results of these combined forces form one of the most important branches of investigation which can occupy the attention of the physical geologist, and in contemplating them, we are at a loss whether most to admire their magnitude, or the immense lapse of time which they must have occupied. It may be worth while to look at the progress of this kind of disintegration, that we may see how wide-spread and constant is the waste that goes on over the world, and how materially the effects of running water are by this means increased. A volume might be written about the decay of rocks, and a most interesting one it would be, but

its authorship would devolve rather on the chemist than the geologist.[1] We can do no more here than merely glance at one or two illustrative examples.

Among the mineral substances that most readily yield to the action of the weather, are the silicates and the carbonates. The rocks containing the former belong in large measure to what we call the igneous class, such as the granites and traps; while those containing the latter form the bulk of our useful stones, such as limestone and sandstone. The removal of alkaline silicates is due to their conversion into carbonates, which are readily soluble in water. Rain falling on a rock in which they are largely present, dissolves a small portion, and carries it into the soil or into streams, and thence to the ocean. Every shower in this way withdraws a minute amount of mineral matter, and tends to leave the harder insoluble grains of the rock standing out on the surface in the form of a loose pulverulent crust, easily washed away. The debris thus formed, where allowed to accumulate, makes an excellent kind of soil known to the Scottish farmers as "rotten rock."

The tourist who has visited any of our granitic districts, such as the south-western parts of Cornwall, the rugged scenery of Arran, or the hills of the Aberdeenshire Highlands, must be familiar with some of the forms of waste which the rocks of these regions display. Mouldering blocks, poised sometimes on but a slender base, and eaten away into the most fantastic shapes, abound in some localities, while in other parts, as for instance at the summit of Goatfell in Arran, the rock weathers into a sort of rude masonry, and stands out in its nakedness and ruin like some crumbling relic of Cyclopean art. In other districts, as in Skye and in the adjoining island of Raasay, the granitic hills are of a still more mouldering material. Their

[1] A German chemist, Bischoff by name, has written two learned volumes in which this subject is discussed (translated into English, and published by the Cavendish Society), valuable for their facts, but not always very safe in their deductions.

summits, white and bald, sometimes rise to a height of fully two thousand feet above the sea, while down their sides are spread long reddish-yellow tracks of debris intermingled with patches of stunted herbage. Every winter adds to the waste, and lengthens the lines of rubbish. Some of these hills form a good field wherein to study the disintegration of granitic rocks, such, for instance, as Beinn na Cailleaich, that rises from the shores of Broadford Bay. Around the eastern base of that mountain there stretches a flat moory district, with a few protruding blocks that have rolled down into the plain. The earlier part of the ascent lies over a region of metamorphic limestone, where the grey weathered masses of the calcareous rock, often like groups of mouldering tombstones, are seen protruding in considerable numbers through the rich soft grass and the scanty brushwood of hazel and fern. Leaving this more verdant zone, we enter a district of brown heath that slowly grows in desolation as we ascend. Huge blocks of syenite—a granitic rock of which the upper part of the mountain entirely consists—cumber the soil in every direction, and gradually increase in numbers till the furze can scarcely find a nestling-place, and is at last choked altogether. Then comes a scene of utter desolation. Grey masses of rock of every form and size are piled upon each other in endless confusion. Some of them lie buried in debris, others tower above each other in a rude sort of masonry, while not a few perched on the merest point seem but to await the storms of another winter to hurl them down into the plain. The ascent of such a region is no easy task, and must not unfrequently be performed on hands and knees. But once at the top, the view is enough to compensate a tenfold greater exertion. Far away to the west, half sunk in the ocean, lie the isles of Eigg, Coll, and Tiree, with the nearer mountains of Rum. North-west, are the black serrated peaks of the Coolins, that stand out by themselves in strange contrast with every other feature of the landscape. Northward, stretches

the great range of syenitic hills, with the sea and the northern Hebrides beyond. Away to the east, across the intervening strait, lie the hills of the mainland, with all their variety of form and outline, and all their changing tints, as the chequered light and shade glide athwart the scene. Southward, the eye rests on the grey wrinkled hills of Sleat, and far over along the line where earth and sky commingle, are the mountains of Morvern, stretching westwards till they end in the bold weather-beaten headland of Ardnamurchan, beyond which lies the blue boundless ocean. The top of Beinn na Cailleaich is flat and smooth, surmounted in the centre by a cairn. Tradition tells that beneath these stones there rest the bones of the nurse of a Norwegian princess. She had accompanied her mistress to "the misty hills of Skye," and eventually died there. But the love of home continued strong with her to the end, for it was her last request that she might be buried on the top of Beinn na Cailleaich, that the clear northern breezes, coming fresh from the land of her childhood, might blow over her grave.

I have already alluded to the wasting away of a trap-dyke. This decomposition arises from the same cause as among the granites—the solution and removal of the silicates. All these trap-rocks are igneous, and seem to have risen from below through open fissures and rents. As they contain a large percentage of felspar—the same mineral that gives to many granites their mouldering character—they may be seen exhibiting every form and stage of decay. Often they stand out in prominent relief from some cliff of soft shale, with a brown surface, picturesquely roughened into spherical masses of all sizes, that give to the rock somewhat the appearance of a hardened pile of ammunition in which ponderous shells lie intermingled with round shot, grape, and canister. Each of the concretionary balls when examined is found to exfoliate in concentric pellicles like the coats of an onion, and you máy sometimes peal off a considerable number before arriving at the central core, which

consists of the hard rock still undecomposed. In this case the process of degradation is aided by the decay of another mineral called augite, which contains a variable percentage of iron, and imparts the peculiar yellowish-brown tint to the weathered rock. Trap-dykes may also be seen in a still more wasted condition, where, in place of protruding from a cliff-line, they recede to some depth and give rise to deep clefts and fissures. An instance of this kind has been referred to in the case of the Spar Cave, and many others may be seen along the same coast-line. The shore there for miles is formed of a low cliff of white calcareous sandstone, fissured by innumerable perpendicular clefts of greater or less width, and sometimes only a yard or two apart. Each of these has once been filled by a dyke of trap, which originally rose up in a melted state, and after having solidified into a compact stony mass, began to yield to the process of decay. In all these and similar cases, the primary cause of the waste lies in the decomposition of the felspar. Rain-water acts in removing the soluble portions, and the harder grains that remain, deprived of the cementing matrix, ere long crumble down and are washed off by the rains. In this way the rock insensibly moulders away, every frost loosening its structure, and every shower carrying away part of its substance.

Among the many objects of interest along a rocky coast some of the more striking are certainly to be found in the curious and often grotesque forms assumed by the weathered cliffs. Above high-water mark and thus away from the dash of the waves, we can often trace the progress of decay among such sedimentary rocks as sandstones and conglomerates. Worn into holes and scars, projecting cusps and tapering pinnacles, or eaten away into the rude semblance of a human form, headless perchance, or into the shape of a huge table poised on a narrow pedestal, the rock affords an endless variety of aspects and a continual source of pleasure. If we chance to light upon any

building constructed out of the sandstone of such cliffs, it is worth noting that the removal of the stone has not deprived it of its mouldering qualities ; nay, that houses erected within the memory of people still living already begin to wear an aspect of venerable antiquity. I remember meeting with an interesting example in the case of an old castle built on a similar rocky coast-line. It stood on a little ness or promontory of dull red stone, washed on all sides save one by the wild sea. The walls, of which but a fragment remained, were built of a dark red sandstone ; but the lapse of centuries had told sadly on their masonry. The stones rose over each other tier upon tier, corroded sometimes into holes and hollows, sometimes into a close honey-combed surface, but the mortar that had been used to cement them together still stood firm and protruded from between the tiers to show, by no doubtful or ambiguous sign, how silently yet how surely the wasting forces had been at work. The scutcheon over the only remaining gateway had been carved out of another kind of stone of a lighter colour and harder texture, and so its grim lions looked nearly as fresh and formidable as when first raised to the place of honour which they still occupied. In this case, as before, the decomposition was owing to the presence of a considerable proportion of soluble matter, which the rains of four centuries had carried away along with the loosened incoherent sandy grains.

Conglomerate or pudding-stone has often a picturesque outline in its decay, more especially if its included fragments have a considerable range of size. Large tracts of this rock exist in various parts of Britain, particularly in Scotland, where the basement beds of the Old Red Sandstone consist of a coarse conglomerate, sometimes several thousand feet in thickness. Such enormous masses form the scenery of a large part of East Lothian, and are found in detached patches across into Peeblesshire and Lanark. In the north, too, the neighbourhood of Inverness and other parts of the same district display conspicuous

conglomerate hills. Unless where laid bare by streams or by the action of breakers, the contour of these hills is rounded and tame, with a scanty covering of short scrubby grass and very few protruding bosses of rock. But where a mountain torrent has cut its way down the hill side, the ravine thus formed exhibits broken walls and pillars of rock made up of rounded balls of every shade and size, cemented by a dark-red or green paste. The cementing material is sometimes clay, sometimes lime, and its variable nature gives rise to a corresponding inequality in the amount and form of decomposition. Where the rounded pebbles are bound together by clay, rains act with rapidity in washing away the cement, and the component balls fall out by degrees, leaving a cliff strangely roughened by protruding knobs, and eaten away into clefts and hollows. When the pebbles are held in a crystallized matrix of lime, they usually remain longer together, and may sometimes be seen standing up in the form of detached rugged pillars that defy all regularity of size or outline, and remind one of a sort of rude grotto-work. Such irregularities become still more marked where to the action of the rains there has been added the spray of the ocean. A coast-line of conglomerate, where the rock rises into cliffs, is always a romantic one; caves, pillars, and ruined walls, all in the same rough grotto style, meet us at every step. Here, too, we can mark the varying effect of the waves upon the lower portions of the rock, eating it into cavernous holes and leaving rugged projecting pinnacles to which the mottled colours of the included pebbles give an additional and peculiar effect.

A cliff of shale seldom shows much of the picturesque, though often a good deal of the ruinous. The rock is easily undermined by streams, and a shale ravine usually exhibits in consequence either heaps of crumbling rubbish, or, where the stream comes past with a more rapid current, perpendicular walls, jointed and laminated, but without much variety of outline. Such cliffs, however, merit the careful attention of the observer,

for from their friability they are most easily decomposed and washed down by streams, to form new accumulations of similar soft argillaceous matter. A shale coast-line sometimes shows cliffs of considerable altitude, as in some parts of Skye and Pabba, where the Lias shales may be seen piled over each other often to a height of seventy or eighty feet, and spreading out along the shore as low flat reefs and skerries, brown with algæ at their seaward ends, and showing on the higher slopes of the beach the characteristic fossils of the Lias—*ammonites*, *belemnites*, and *gryphææ*—crowded together by hundreds. The action of the decomposing forces has operated more effectually on the soft material of the shale than on the hard crystalline lime of the included shells, so that the latter stand out in relief from the dull-brown surface of the rock, and from their numbers and prominence form one of the most marked features of the coast-line.

Probably few have ever visited a limestone district without marking the manner in which that rock yields to the action of the elements, whether in an inland part of the country where rivers have cut deep gullies through the rock, or along some exposed shore where the stone has been wasted by a still ruder assailant. An exposed cliff of hard homogeneous limestone weathers into deep clefts and holes ; the entire surface assumes a pitted appearance, somewhat like a sandy beach after a shower of rain, and the planes of stratification, or lines formed by the parallel junction of the beds are often worn away until the rock looks not unlike a piece of old masonry, in which the mortar has decayed and dropped out, leaving the angles of the stones to get wasted and rounded by the action of the weather. In many districts, too, where the rock is richly fossiliferous, the broken joints of encrinites along with corals and shells may be seen crowded together by myriads, their hard skeletons protruding from the wasted rock in such a way as to show that the stone can contain very little else. By this means we often

learn that a limestone bed is nothing but an old sea-bottom, where the calcareous sediment was mainly derived from broken stone-lilies, corals, and shells, though if we break off a piece of the rock the internal fracture may show very little or no trace of any organic structure. And hence if the geologist would form an accurate conception of the origin and structure of many of the stratified rocks, he must study them not in hand specimens neatly trimmed and arranged along the shelves and drawers of a cabinet, nor even in the ponderous blocks daily exhumed by the quarryman, but along some surf-beaten cliff-line or down some precipitous ravine where the rock for centuries has been exposed to the wear and tear of the elements.

Limestones and other calcareous formations are liable to more than ordinary decay, for, as we have seen above, percolating rain-water constantly carries away mineral matter from their subterranean portions. Accordingly, in some parts of the country, as for instance in Yorkshire, the interior of such rocks has been eaten away into great caverns by this form of decomposition.

Some remarkable examples occur in the island of Raasay, one of the north-eastern Hebrides. Its eastern margin shoots up from the sea to a height of over 900 feet, the cliff-line being formed of a calcareous grit as perpendicular as a wall, and fissured by deep chasms and rents. The narrow table-land between the edges of this cliff and an abrupt ridge that rises behind, is perforated by innumerable holes and clefts, into which if a stone be thrown it may be heard for several seconds rumbling far below. The edges of these pitfalls are often fringed with ferns, rushes, and long grass, so as to be nearly hidden, and it requires no little caution to traverse this elevated region in safety. Innumerable sheep have been lost by falling into the subterranean abysses, and even the wary natives seem to have sometimes lost their footing. A story is told of a woman who had crossed to the other side of the island for the purchase of

some commodities, and returning by the high grounds had got nearly within sight of her own cottage, when by some unlucky accident she took a false step and instantly disappeared. Unfortunately her errand had been performed alone, so that some time elapsed ere she was missed. The search continued unremitting for two days, but no trace of the missing traveller could be found. At last on the third day her figure was seen creeping slowly along the road not many hundred yards from her own door. It appeared that she had first slid down a sheer height of about fifty feet, when her further passage was intercepted by the sides of the fissure. During the earlier part of her confinement she strove hard to re-ascend the chasm, and it was not until, the effort seeming fruitless, she had begun to resign herself to despair, that a glimmering of light from below induced her to attempt a descent. This proved no easy matter, and occupied many weary hours of labour and suspense ; but at length she succeeded in worming herself to the bottom, and crawled out more dead than alive only a little way from her home. There still stand perched on some of these precipitous cliffs the remains of a few villages, the inhabitants of which were accustomed to tether their children to the soil, whence one of the hamlets received in Gaelic the soubriquet of Tethertown. Many a valuable commodity disappeared by rolling over the cliff, and I have been assured that it was no unfrequent occurrence for a pot of potatoes capsized at the doorway to tumble down the slope and make no stop until safely esconced at the sea-bottom.

The process whereby these fissures and caverns originate is the same as that noticed already in the Spar Cave. Water containing an impregnation of carbonic acid filters down through cracks and fissures of the calcareous rock, dissolving out in its passage a portion of the lime which it eventually carries back to the surface, and either deposits there or transports into streams, and thence to the sea. Thus atom by atom is removed wherever the perco-

lating water reaches, until in the course of ages an irregular cavern of greater or less extent is produced. The decomposition of limestone at the surface results from the same kind of action, that of carbonated water. Every shower of rain insensibly carries away a fraction of the constituent parts of the rock, so that the size and form of detached blocks as well as of exposed cliffs is constantly changing. How often do we see the same decay going on with a melancholy rapidity among the exposed marble tombstones of our churchyards. In a few years the tablet gets worn and furrowed as though it had stood there for centuries. Eventually, too, the inscription becomes effaced, and perhaps ere the bones of the deceased have mouldered away and mingled with their kindred dust, the epitaph that recorded for the admiration of posterity his many virtues and his vigorous talents, has faded from the stone—often, alas! only too fit an emblem of how speedily the memory of the dead may fade away out of the land of the living.

CHAPTER IX.

Mechanical forces at work in the disintegration of rocks—Rains—Landslips—Effects of frosts—Glaciers and icebergs—Abrading power of rivers—Suggested volume on the geology of rivers—Some of its probable contents—Scene in a woody ravine—First idea of the origin of the ravine one of primeval cataclysms—Proved to be incorrect—Love of the marvellous long the bane of geology—More careful examination shows the operations of Nature to be singularly uniform and gradual—The doctrine of slow and gradual change not less poetic than that of sudden paroxysms—The origin of the ravine may be sought among some of the quieter processes of Nature—Features of the ravine—Lessons of the waterfall—Course of the stream through level ground—True history of the ravine—Waves and currents—What becomes of the waste of the land—The Rhone and the Leman Lake—Deltas on the sea-margin—Reproductive effects of currents and waves—Usual belief in the stability of the land and the mutability of the ocean—The reverse true—Continual interchange of land and sea part of the economy of Nature—The continuance of such a condition of things in future ages rendered probable by its continuance during the past.

The forms of decomposition noticed in the last chapter were chiefly of a chemical kind. Their effects were observable alike on the surface of the earth and below ground; in the latter case we saw them excavating caverns and long irregular chasms, in the former we noted the production of debris which if undisturbed went to the formation of soils. It must be borne in mind however, that in these operations other forces than simply those of a chemical kind come into play. The percolation of water and the removal of insoluble particles on the exposed parts of rocks rank as mechanical processes. So also do those by which new surfaces of mineral masses are brought within the sphere of the chemical agencies, such as the action of frosts, rains, rivers, and waves. In short, as already noticed, any subdivision of the forces at work in effecting the decomposition of rocks must ever be more or less arbitrary; but it remains

nevertheless useful, if we bear in mind that the exactly defined boundary lines are of our making, not Nature's. With this caution we may proceed to examine what are termed the mechanical agencies in the disintegration of mineral masses, and in so doing, we shall find that the chemical forces are not less helpful to the mechanical than the latter to the former.

First, we may notice the effect of rains in washing away the disintegrated particles to lower levels or into river-courses whereby fresh portions of rock become exposed to the decomposing forces. Rains also act powerfully in altering the form of cliff-lines and steep declivities, especially where these consist more or less of friable earthy matter. After a long continuance of wet weather, I have seen the abrupt sides of a river-channel that were formed of a stiff blue clay completely cut up by rents of various dimensions, whereby large masses had subsided many feet, while others had rolled down altogether and lay in the bed of the stream where they were undergoing a rapid abrasion. The cause of this alteration was obvious. The rains pouring down from the sloping grounds on either side of the river had excavated deep channels on the abrupt face of the cliffs, while a considerable quantity of water finding its way through the soil, had permeated through joints and crevices in the clay some feet from the edge of the bank. By the combined operation of these causes, masses of clay several yards in extent lost their cohesion and either settled down a few feet, or found their way to the bottom. Such landslips are of frequent occurrence where large masses of rock of a hard compact nature rest upon loose shales and clays more or less inclined. Whole hills have been known to be hurled in this way into the valleys below.

But these results become perhaps still more marked where to the ordinary operations of water there are added those of intense frost. The effects of a severe winter (such, for instance, as a Canadian one), in loosening the particles of rocks and facilitating the breaking-up of large masses, must be ranked among the most

powerful agencies of nature. In such a season, the percolating water with which nearly every surface-rock is charged becomes frozen, and in the act of congelation expands. The result of this dilatation is to exert great pressure on the particles of the rock, and thereby loosen their cohesion. When thaw comes the frozen liquid contracts again, but the loosened particles have no such elastic power, and so, having lost hold of each other, crumble down. If the season be a changeable one, frost and thaw quickly alternating, the amount of waste produced becomes very great. Not only is the outer surface of the stone decomposed, but the water filtering through the joints of the rock freezes there, and thus on the arrival of milder weather vast masses become detached from the cliffs, and roll down, to be worn by the grinding action either of waves or of rivers, as the case may be. Spring at last sets in with its warmth and its showers; the snow rapidly melts away; the whole country streams with water; every valley and hollow has its red turbid rivulet, that bears a burden of muddy sediment into the nearest river; and thus the loosened portions of the rocks get washed away down to sea, leaving a new surface for the action of next winter. We can easily understand, therefore, that in certain regions the combined effects of frost and thaw may work in the course of ages changes of almost inconceivable extent, and that the agency of ice must be not less varied and important on the land than, in the case of the boulder clay, we found it to be in the ocean.

Besides this action in winter, which goes on more or less in every country wherever the temperature sinks sufficiently low to permit of the freezing of water, ice effects many changes on the surfaces of rocks when it takes the form of glaciers and icebergs. We have already noted the operation of a glacier during its slow progress in crushing down large fragments of stone, scratching and abrading the rocks over which it passes, and eventually producing a vast quantity of mud, which is car-

ried down by streams to form new accumulations either in lakes or seas. We have also marked the effects of the drifting iceberg in materially modifying the contour of submarine hills, and depositing over the ocean-bottom mud, gravel, and boulders. Nothing further, therefore, need be done here than simply to keep these agencies in view, as playing an important part in the disintegration of rocks.

Another highly interesting aqueous action is that of streams and rivers, in scooping out for themselves channels through sometimes the hardest and most solid rock. Such effects may be seen all over the globe, in the old world and in the new, in the bed of the tiniest rivulet, as well as in the course of the mightiest river. And accordingly, in all the long list of geological agents, we find none so well known and so often described alike by poets, historians, and scientific writers, as well in ancient as in modern times. What a delightful volume might be written about the geology of rivers! It would, perhaps, begin with that "great river," the Euphrates, along whose green banks lay the birthplace of the human race, tracing out the features of its progress from the ravines and cataracts of Armenia, with all their surrounding relics of ancient art, down into the plains of Assyria, amid date-palms and Arab villages, onwards to the mounds of Nineveh and Babylon, and thence to the waters of the Persian Gulf. Well-nigh as remote, and perhaps still more interesting in its human history, would be the story of the Nile. We should have to follow that river from the mystic region of its birth,[1] marking the character of the rocks through which winds its earlier channel, and the effects upon them of the floods of untold centuries; it would be needful, too, to note the influence of the waters on the lower grounds, from where the stream flows over the cataracts of Syene, down through the alluvial plains of Egypt; and lastly, the concluding and per-

1 "Fontium qui celat origines Nilus"—a description not less true now than in the days of the Sabine bard.

haps most onerous part of our labour would be the investigation of the delta, marking its origin and progress, its features in ancient times, as made known to us in the graphic chapters of Herodotus, and the changes which the lapse of more than twenty centuries has since wrought in its configuration. The rivers of Europe would detain us long, not less perhaps by their historic interest than by the variety and attractiveness of their physical phenomena. One could scarce help lingering over the Rhine, with its source among Alpine glaciers, its lakes and gorges, its castles and antique towns ; and when once the narrative entered the classic ground of Italy, it would perhaps become more antiquarian than geological. The ravine of Tivoli, for instance, would certainly lay claim to a whole chapter for itself, with its long-continued river action, its ancient travertin, its beautiful calcareous incrustations, and above all its exquisite scenery.

> "Domus Albuneæ resonantis,
> Et præceps Anio, ac Tiburni lucus, et uda
> Mobilibus pomaria rivis." [1]

And when could we exhaust all that might be said about the rivers of our own land ?

> "Of utmost Tweed, or Ouse, or gulfy Dun,
> Or Trent, who, like some Earth-born giant, spreads
> His thirty arms along the indented meads
> Or sullen Mole, that runneth underneath ;
> Or Severn swift, guilty of maidens' death ;
> Or rocky Avon, or of sedgy Lee ;
> Or coaly Tyne, or ancient hallow'd Dee ;
> Or Humber loud, that keeps the Scythian's name ;
> Or Medway smooth, or royal-towered Thame."

Passing to the new world, a vast field would spread out before

[1] "Albuna's grey re-echoing home,
And Anio, headlong in his foam,
And grove of Tivoli,
And orchards with their golden gleam,
Whose boughs are dipping in the stream
That hurries to the sea."
HOR. *Carm.* I. vii. 12.

us: the Mississippi, the Atchafalaya, the Ohio, the St. Lawrence, the Amazon, and many other rivers that in some cases rise high among the regions of perpetual snow, and after traversing large areas of country in the temperate zone, fall into the waters of tropical seas. By studying such examples of river-action and delta-formation as are presented by these gigantic streams, we should arrive at some conception of the conditions anciently at work in producing our present coal-fields. Nor would our researches assume aught like completion until after a scrutiny of all the larger and more important rivers of the globe. Such a work could be undertaken, perhaps, only by another Humboldt. Its successful accomplishment would certainly insure the highest renown to its author, and incalculable benefits to science.

From what we have seen of the wide waste and decay everywhere in progress on the solid lands of our planet, it becomes no difficult matter to perceive what a number of agencies must be at work in the formation of a river channel. Let the reader take his stand in some wooded ravine, where the shelving rocks on either side are hung all over with verdure, and a tiny streamlet murmurs on beneath with a flow so quiet and gentle as scarcely to shake the long pendant willow branches that dip into its surface, while the polished pebbles that strew its bed lie unmoved by the rippling current that glides over them. If in the midst of such a scene the question were to arise in his mind, How came this deep, narrow ravine into existence? what answer would in all likelihood be the first to suggest itself? His eye would scan the precipitous walls of the dell, with their rocks cleft through to a depth of perchance fifty feet. It would require no great scrutiny to assure him that the beds on the one side formed the onward prolongations of those on the other, and that consequently there must have been a time ere yet the ravine existed, when these beds stretched along unbroken. Satisfied with these results, his first impulse might be

to bethink him of some primeval earthquake, when the solid land rocked to and fro like a tempested sea, and broke up into great rents and yawning chasms. Into one of these clefts he might suppose the little streamlet had eventually found its way, moistening the bare and barren rocks, until at length their surface put on a livery of moss, or lichen, or liverwort, and the birch, the alder, and the willow, found a nestling-place in their crevices. Such a view of the origin of the woody dell would be certainly a very natural one, and in some instances might be sufficiently correct, but in the present case it will not explain the phenomena. If the reader will kindly permit me to visit the locality in his company, perhaps we may be able to light upon the true explanation, and see a few appearances worthy our attention.

First, then, how can we make sure that no convulsion of nature has produced a rent in the rocks, and so helped the streamlet to a channel? a simple question that may be well-nigh as simply answered. We stand in the centre of the dell on a broad ledge of stone, round whose well-worn sides the rivulet is ever eddying onwards. The block consists of a pale sandstone lying in a bed about three feet thick, that dips gently down the stream and underlies a seam of dull, soft, blue shale, full of small shells. We trace the edge of this sandstone bed across to the left-hand side of the ravine, and away up into the precipitous cliff, till it is lost amid the ferns and brushwood. There can be no doubt, therefore, that the ledge on which we were but now standing is a continuous portion of the rocks that form the left side of the ravine. Returning again to the centre of the stream, we proceed to trace out the course of the other end of the same bed, and find that it, too, strikes across to the rocks on the right-hand side without a break or fissure, and passes up into the cliff, of which it forms a part. Clearly, then, the sandstone bed runs in an unbroken, unfissured line, from the one side to the other, and the rocks of either cliff form one

continuous series. There occurs no break or dislocation, which, of course, there must have been had the ravine owed its origin to any subterranean agency. And so we come to conclude that no great cataclysm in primeval times, no yawning abyss, or gaping chasm, has had anything whatever to do with the formation of our deep sequestered dell. What then? "Whither shall we turn," you ask, "to find another agency equally grand and powerful in its operation and mighty in its results?"

Stay, gentle reader. That craving for the grand and the sublime, that hungering after cataclysms and convulsions, that insatiable appetite for upheavals, and Titanic earth-throes, and all the mightier machinery of Nature, has done no little mischief to geology. Men have reasoned that gigantic results in the physical structure of the earth must have had equally gigantic causes operating in sublime conflict and in periodic paroxysms, now heaving a mountain chain to the clouds of heaven, now swallowing up a continent in the depths of the sea. Happily such extreme notions are fast passing away, though the old tendency in a modified form still abounds. A closer scrutiny of Nature as she actually shows herself, not as theorists fancy she should be, has revealed to us that her operations are for the most part slow, gradual, and uniform, and that she oftentimes produces the mightiest results by combinations of forces that to us might seem the very emblems of feebleness and inactivity. In place of sudden paroxysms she demands only an unlimited duration of time, and with the aid of but a few of these simple, tardy agents, she will eventually effect results perchance yet more gigantic than could be accomplished even by the grandest catastrophe. Nor in thus seeking to explain the past by defining what seems the usual mode of Nature's operations in the present, do we, as is sometimes alleged, deprive them of their high poetic element. Assuredly there is something thrilling to even the calmest imagination in contemplating the results of vast and sudden upheavals, in picturing the solid crust

of the earth heaving like a ground-swell upon the ocean, in tracing amid

> "Crags, knolls, and mounds, confusedly hurl'd,
> The fragments of an earlier world;"

and in conjuring up visions of earthquakes, and frightful abysses from which there ever rose a lurid glare as hill after hill of molten rock came belching up from the fires below. But while far from denying that such appearances may have been sometimes seen during the long lapse of the geological ages, and that they give no little vividness and sublimity to a geological picture, we claim for the doctrine of the tranquil and uniform operation during past time of existing laws and forces, an element not less poetic. In the former case the pervading idea is that of unlimited expenditure of power, in the latter that of unlimited lapse of time. In the one case the action is Titanic but transient, in the other it is tranquil but immensely protracted. The two doctrines in this way counterbalance each other; yet I cannot but think that however impressive it may be to stand in some lone glen, and while gazing at its dark jagged precipitous cliffs, to dream about the paroxysmal convulsions of some hour far back in the distant past, the scene becomes yet more impressive when we look on its nakedness and sublimity not as the sudden and capricious creation of a day, but as the gradual result of a thousand centuries. These cliffs may once have been low-browed rocks rising but a little way out of a broad grassy plain, and serving as a noontide haunt for animals of long extinct races. Thousands of years pass away and we see these same rocks higher and steeper in their outline, brown with algæ and ever wet with surf, while around them stretches a shoreless sea. Ages again roll on, and we mark still the same rocks shooting up as bleak crags covered with ice and snow. Another interval of untold extent elapses, and rock, snow, and ice have all disappeared beneath a broad ocean cumbered with ice-floes and wandering bergs.

Again the curtain drops upon the scene, and when once more it rises, the cliffs stand out in much the same abrupt precipitous aspect with that which they now present, save that their bald foreheads look less seamed and scarred than now, and their dark sides show no trace of bush or tree. The white cascades that to-day pour down from their summits and sides—seeming in the distance like the white hairs of age—are insensibly deepening the scars and furrows on these ancient hills, and thus slowly but yet surely carrying on the process of degradation and decay. Musing on all this long series of stages in the formation of one single cliff-line, is there not something more sublime, something yet more impressive than if we pictured but the chance random result of the gigantic paroxysm of an hour?

Let us not be deterred then from seeking an explanation of the origin of the ravine among some of the quieter and more unobtrusive forces of Nature. Give them but an unlimited period to work in and they will abundantly satisfy all our demands.

We return again to the rocky ledge in mid-channel, and proceed to ascend the course of the stream, marking as we go the changes in the character and features of the stone that forms the cliff on either hand. We come to a bare part of the ravine where brushwood and herbage find but a scanty footing and where accordingly the rocks can be attentively studied. The face of the escarpment shows a number of beds of pale grey sandstone alternating with courses of a dark crumbly shale. The sandstones being harder and firmer in texture stand out in prominent relief while the shales between have been wasted away, covering the bottom of the slope with loose debris. We can mark too that, as this decay goes on, the harder beds continually lose their support, cracking across chiefly along the lines of joint, and rolling down in huge angular blocks into the stream. In truth we cannot doubt that every year adds to this decay and thus slowly widens the dell, for the broken fragments do not form in heaps

over the solid rock below so as to protect it from the weather, but are evidently carried away by the stream and hurried down the ravine onwards to the sea. From what has been said above relative to the disintegration of rocks by percolating water, frosts, and other causes, the reader will easily see how this rotting away of the sides of the ravine must be carried on; and he will not fail to mark that here we have at work an agency not yet considered, that of running water. The effects of the weather are seen in the crumbling, ruinous cliffs overhead; the effects of the streamlet are observable in the continual removal of the rubbish whereby a fresh surface is ever exposed to the decomposing forces, while at some points we can mark the water actually undermining an overhanging part of the cliff from which there are ever and anon vast masses precipitated into the channel where eventually they get worn down and carried away out to sea. "Still," you may remark, "these forces are at work only in widening a channel already made. How was the ravine formed at first?"

We continue our ascent. A scrambling walk through briars and hazel-bushes, sometimes on rocky ledges high among the cliffs, sometimes among the prostrate blocks that dam up the stream, brings us at last full in front of a sparkling waterfall that dashes over a precipitous face of rock some twenty feet high. The appearances observable here deserve a careful attention. Our eyes have not been long employed noting the more picturesque features of the scene ere they discover that the dark-brown band of rock forming the summit of the ledge over which the water tumbles is continuous all round the sides of the dell. There is consequently no break or dislocation here. Approaching the cascade we note the rock behind it so hollowed out that its upper bars project several feet beyond the under ones. In this way the body of water is shot clear over the top of the cliff without touching rock till it comes splashing down among the blocks in the channel. And yet this hollowed

surface is never dry ; the spray of the fall constantly striking on it keeps it always dank and dripping. In some parts the rock stands out bare and worn, while on the less exposed portions there gathers a thick green scum which is replaced on the drier ledges by the soft cellular leaves of the liver-wort. Now our examination of the influence of percolating water upon even the hardest rocks teaches us that this moist soaked surface is just the very best condition for favouring the decay of the rock. Nay more, the green vegetation that mantles over the stone serves to prevent the water from running off too rapidly, and keeps the rock in a still more moist state than would otherwise happen. So that the portion of sandstone behind the cascade comes to be in a still more favourable situation for speedy decay than the ledge over which the water is rapidly driven. We can see, therefore, how in the lapse of years the corrosion may go on until the upper projecting part of the cliff loses its support and falls with a crash into the rocky pool below, while the form of the waterfall becomes thus greatly altered, and new surfaces are exposed to the wear and tear of the stream.

But we have not yet exhausted all that the rocks at the cascade can teach us. By dint of some exertion we climb the cliff and gain the upper edge of the fall. The rocks that form the bed of the stream are now seen to be deeply grooved and worn, every exposed surface having a smoothed blunted aspect. We can mark how the stone has split up along the natural lines of joint, whereby great facility is given to the removing power of the current, and how large irregular angulated blocks become detached and are swept down the stream. In not a few parts, too, we may notice circular holes of greater or less depth, in the bottom of each of which lie perhaps a pebble or two, that with a constant gyratory movement, caused by the eddying water, have eaten their way downwards into the solid rock. When the stream is in flood and comes roaring down the rocky gorge bearing along with it a vast amount of mud, gravel, and

stones, one can easily see how the friction of the transported material must wear down the hard bed and sides of the channel, and how this process repeated month after month and year after year, must aid the decomposing forces in scooping out a deep ravine. From the cascade the ascent of the stream becomes steeper and the run of water is consequently more rapid. Soon however we emerge from the woody copse, and find ourselves on a flat alluvial cultivated plain through which the rivulet winds in a tortuous meandering course, bending back upon itself into loops that almost meet and well-nigh form broad flat islets. Strolling along this winding route we can mark the effects of the stream in eating away the soft clay and sand at one part of the bend and piling them up at another. Such loose material can present but little resistance to a stream swollen with rains, and consequently a large quantity of the mud and gravel along with the interspersed boulders must be swept away down into the dell at every season of flood. The matter thus removed will of course be still further comminuted in its passage, and at the same time will help to grind down the hard rock surfaces over which it is driven.

Here then may be found the whole history of the ravine. Originally the streamlet wound its devious course through a flat alluvial country with a channel sunk but a foot or two below the level of the plain. Such continued its character till it reached a low bluff, down which the water flowed more rapidly to gain a second level undulating region. The part of this bluff crossed by the stream was ere long bared of its covering of soil and clay, and the rock below came to be washed by a group of little cascades. Once exposed to the decomposing and disintegrating forces, the stone soon began to decay and the cascades ere long merged into one. By slow degrees the rock gave way and the waterfall retreated from the bluff. For perchance thousands of years the same process has been going on, now with greater, now with less rapidity, according to the nature

of the rocks encountered and other modifying causes, until the fall has eaten its way back for well-nigh three miles and scooped out a wild rocky gorge some fifty or sixty feet deep. This is but a solitary and insignificant instance of what may be seen all over the world, for the process remains the same whether we stand beside a tiny rivulet in some lone Highland glen or listen to the roar of the falls of Niagara.

There is but one other principal agency at work in the demolition of rock-masses, the waves and currents of the ocean. But we have already noted the effects thus produced, and need not now retrace our steps further than to recall the vast amount of devastation which can be shown to have been effected in our own country by marine causes, both in breaching the existing shores and in scooping out valleys and grinding down hills at former periods when the land was either rising above or sinking below the level of the sea.

Having now satisfied ourselves that there goes on all over the world an incessant waste of the solid lands, that the disintegrated debris is washed down by rains and transported seawards by rivers, and that the waves are ever eating their way into the iron-bound coast-line as well as into the low alluvial shore, we naturally come to ask the result and end of all this decay. What becomes of that vast amount of mineral matter annually removed from the land? To be able to answer this question clearly and distinctly, let us look for a little at what takes place in lakes, at river-mouths, and in open sea.

The river Rhone rises among the Bernese Alps, and after a course of about 100 miles through the Canton of Valais, it enters the upper end of the Lake of Geneva. Its waters, where they mingle with those of the lake, are muddy and discoloured, but where they pass out at the town of Geneva are limpid and clear. The mud, therefore, which they bring into the lake must be deposited there, and as the stream may have continued to flow for thousands of years, we may reasonably expect to find some

trace of the large amount of sediment necessarily deposited during the whole or part of that long period. Accordingly, careful examination of the Lake of Geneva has shown that such accumulations have really been formed, and that their progress and amount during part of the historic period can be approximately calculated. Where the turbid current of the Rhone enters the still water of the lake, the mud slowly sinks to the bottom. In the lapse of centuries layer after layer has been thrown down, rendering the lake at this part sensibly shallower, until a large area or delta has been filled up and converted into a flat alluvial plain. Thus, a town which in the time of the Romans formed a harbour on the water's edge, now stands more than a mile and a half inland. This new-formed land is entirely the work of the stream, and if we could obtain a complete section of it from the surface to the bottom, "we should see a great series of strata, probably from 600 to 900 feet thick (the supposed original depth of the head of the lake), and nearly two miles in length, inclined at a very slight angle." These strata, which are said to have taken about eight centuries to form, "probably consist of alternations of finer and coarser particles; for, during the hotter months, from April to August, when the snows melt, the volume and velocity of the river are greatest, and large quantities of sand, mud, vegetable matter, and drift-wood, are introduced; but, during the rest of the year, the influx is comparatively feeble, so much so that the whole lake, according to Saussure, stands six feet lower."[1] If the present conditions continue for a sufficient length of time, the lake may be eventually filled up with mud, sand, and gravel, deposits that would eventually harden by pressure into shale and sandstone. So that the day may yet arrive when the blue waters of the Leman lake shall have passed away, when the Rhone perchance may have ceased to flow or found its way by some other channel, when the peasant may guide the plough where now the boatman plies

[1] Lyell's *Principles of Geology*. Ninth edition, p. 252.

the oar, and when the geologist shall trace out in quarries and excavations the successive deposits of hardened sediment with their lacustrine shells and drift-wood, and, musing on the changes of which they are the silent yet impressive witnesses, may sit down to pen a record of the gradual extinction of the Leman lake on that classic ground where an immortal historian described the decline and fall of the empire of Rome.

The alluvial matter deposited by the Rhone at its entrance into the Lake of Geneva suffers perhaps no change when it once reaches the bottom. Layer after layer accumulates tranquilly, without disturbance from surface currents or other causes, so that the renovating effects of the stream have here every advantage. It is otherwise, however, where a delta gathers at the mouth of a river upon the sea-margin. There tides and currents are ever demolishing what the stream has piled up. Often, too, owing to the prevalence of high winds from seawards, the river is dammed up for leagues, and the waters of the ocean encroach far on the delta, mingling in this way marine remains with those that are fluviatile or terrestrial. But with these modifications the process of delta-formation remains essentially the same, both in lakes and at the sea. The vast quantities of sand and gravel transported by rivers during the flood-season sink to the bottom as soon as the motion of the water will permit. This takes place at the shore, where eventually wide tracts of low alluvial land encroach upon the sea, covered with marshes and overgrown with vegetation. A section of any of these deltas, obtained in boring for water, shows a succession of sands and clays, with occasionally a few calcareous beds and quantities of peaty matter formed of vegetation either drifted or that grew on the spot.[1] If, now, a sufficient amount of matter were piled over these loose incoherent strata, they would

[1] The structure of maritime deltas, especially their relation to the growth and entombment of forests, will be more fully alluded to in a subsequent chapter, when we come to inquire into the origin of a coal-field.

eventually become as hard and compact as any of our ordinary building stones. The sand would subside into a firm compact sandstone; the clay, in like manner, would consolidate into fissile shale; the peat would become chemically altered into coal; the calcareous seams would take the form of layers of limestone; while the leaves, twigs, branches, and trunks, dispersed through all the beds, would get black and carbonized, so as precisely to resemble the lepidodendra, calamites, stigmariæ, &c., of the carboniferous rocks. And thus might a mass of fossiliferous strata, thousands of feet deep and thousands of square miles in extent, be amassed by the prolonged operation of a single river.

It often happens that a delta is prevented from extending further seawards owing to the prevalence of some marine current that comes sweeping along the coast-line and cuts away the accumulations thrown down by the river. The sediment thus removed is often carried to great distances, and eventually settles down as a fine mud along the floor of the sea, entombing any fucoids, infusoria, shells, corals, fish-bones, or other relics that may lie at the bottom.

He who has witnessed a storm along a rocky coast-line, has marked the breakers battering against the weather-bleached cliffs, and heard the thunder-like rattle of the shingle at the recoil of every wave, needs not to be told how vast an amount of sediment must in this way be formed. The pebbles of the beach are ground down still smaller, the sand produced by their friction finds its way to a lower level, while the finer particles taken up by the water are borne out to sea, and if a current traverse the locality may be transported for leagues, till they at last settle to the bottom. The floor of the sea is consequently always receiving additions in the form of fine mud—the waste of the land—derived either from breaker-action, rivers, or icebergs, so that a series of marine deposits exactly similar to those we find among the rocks of our hills and valleys, must

be constantly in the course of formation. If circumstances be favourable, the shingle of the beach may eventually either be covered over or reach a part of the sea undisturbed by currents or waves, and then consolidate into what we call conglomerate or pudding-stone. The sand, as before, becomes sandstone, and the mud laminated shale or hardened clay. These deposits may go on forming for thousands of years, until at last some slow elevation or some sudden upheaval of the ocean bed brings them to the light of day as part of a new continent. Thus exposed they would differ in no respect from rocks of a similar kind now visible, and the geologist, in tracing out their origin and history, would have no hesitation in ranking them among the ordinary marine formations of the globe.

In fine, we cannot quit the subject without being convinced that these ceaseless changes afford one of the grandest examples of that continuous series of mutations—cycle and epicycle—which has been already alluded to as a distinguishing feature in all the operations of Nature. We are accustomed to think and speak of "the everlasting hills." We look on the solid lands whereon we dwell as the emblem of all that is stable and steadfast, and on the boundless ocean as the type of all that is unsteady and changeful. The traveller who stands on those plains where the human race was cradled, marks still the same valleys with their winding rivers, still the same rocks and hills, still the same blue sky overhead. The dust of centuries has gathered over the graves and the dwellings of the early races, yet the covering is but thin, and if we could conjure from their resting-place some of these venerable patriarchs, they might perhaps see little or no change on the haunts of their boyhood. We feel it otherwise, however, when we contemplate the ocean. In sunshine and in storm its surface never rests. The wave that now breaks against some bald headland of our western shores may have come sweeping across from the coast of America, and the broad swell that rolls into surf along the

shores of Newfoundland may have travelled from the frozen seas of the North Pole. And so it has ever been; the "far resounding sea" of Homer is the "far resounding sea" still; and the "countless dimpling of the waves," invoked in his agony by the chained Prometheus, remains restless and playful as ever.

"Firm as a rock," and "fickle as the sea," have therefore become proverbs of universal acceptance. Yet when we investigate the matter as we have done in this and the preceding chapter, it appears that an exactly opposite arrangement would be nearer the truth. It is the sea that remains constant—

> "Time writes no wrinkle on its azure brow;"

while the land undergoes a continual change. Hills are insensibly mouldering away, valleys are ever being widened and deepened, rocky coasts and low alluvial shores suffer a constant abrasion, while even within the bowels of the earth the process of decomposition uninterruptedly proceeds. And thus, in place of remaining unchanged from the beginning, we know of nothing more mutable than the land on which we dwell, so that if the waste everywhere so apparent were to go on unchecked or unmodified, island and continent would eventually disappear beneath the waves. Here, however, another principle comes into operation. The debris removed from the land, as we have seen, is not annihilated. Slowly borne seawards, it settles down at river mouths or on the floor of the ocean as an ever-thickening deposit, which eventually hardens into rock, as solid and enduring as that whence it was derived. But it does not always remain there. Owing to the action of subterranean agencies with which we are but slightly acquainted, different parts of the sea-bottom are continually rising. Sometimes this process goes on very slowly, as along the shores of Sweden, where the coast has been ascertained to emerge in some localities at the rate of about thirty inches in a century; sometimes with

prodigious rapidity, as on the coast of Chili, where the land was upheaved from two to seven feet in a single night. There can thus be no doubt that the mysterious agency which produces earthquakes and volcanoes on the land affects equally that portion of the earth's crust covered by the waters of the ocean, and must be ceaselessly employed in elevating large areas of sea-bottom into new continents, that will ere long become clothed with vegetation and peopled with animals. In contemplating, therefore, the constant decay in progress on the surface of the land, we see not a mere isolated process of waste, but a provision for future renovation. The sandstone cliffs of the shore are battered down and their debris carried out to sea, but when sea-bottom comes to be land-surface, they may be sandstone cliffs again, lashed once more by the breakers, and once more borne as sediment to the depths of the sea. And thus, in what may seem to us sublime antagonism, land is ever rising in the domain of ocean, and ocean ever encroaching on the regions of land. No sooner does a new island, or mountain peak, or wide area of continent, appear above the waves, than the abrading agencies are at work again. Rain, air, frost, rivers, currents, breakers, all begin anew the process of destruction, and cease not until the land has utterly disappeared, and its worn debris has sunk in mid-ocean to be in process of time once more dry land, and suffer another slow process of obliteration.

Such is the economy of nature around us now, and that such will continue to remain the condition of things in the future, we can affirm with probability from a consideration of the history of the past. The geologist can point to masses of rock several miles in thickness, and occupying a large area of the globe, formed entirely of the worn debris of pre-existing formations. The very oldest rocks with which he is acquainted are made up of hardened sediment, pointing to the existence of some land, even at that early period, worn down by rivers or

wasted by the sea. During all the subsequent ages the same principles were at work, and now well-nigh the only evidence of the geological periods is to be gathered from the layers of sediment that successively settled down at the sea-bottom. The records which it is the task of the geologist to decipher, are for the most part written in sand and mud—the deposits of the ocean, for in by far the larger number of formations into which the stratified part of the earth's crust has been divided, and which form his only guide to the history of the past, he can detect no trace of land. Hill and valley have alike disappeared, and the character of their scenery and inhabitants he can often but dimly conjecture from the nature of the sediment and of the drifted terrestrial relics that may chance to be found among strata wholly marine.

CHAPTER X.

The structure of the stratified part of the earth's crust conveniently studied by the examination of a single formation—A coal-field selected for this purpose—Illustration of the principles necessary to such an investigation—The antiquities of a country of value in compiling its pre-historic annals—Geological antiquities equally valuable and more satisfactorily arranged—Order of superposition of stratified formations—Each formation contains its own suite of organic remains—The age of the boulder defined by this test from fossils—Each formation as a rule shades into the adjacent ones—Mineral substances chiefly composing the stratified rocks few in number—Not of much value in themselves as a test of age—The Mid-Lothian coal-basin—Its subdivisions—The limestone of Burdiehouse—Its fossil remains—Its probable origin—Carboniferous limestone series of Mid-Lothian—Its relation to that of England—Its organic remains totally different from those of Burdiehouse—Structure and scenery of Roman Camp Hill—Its quarries of the mountain limestone—Fossils of these quarries indicative of an ancient ocean-bed—Origin of the limestones—Similar formations still in progress—Coral-reefs and their calcareous silt—Sunset among the old quarries of Roman Camp Hill.

Among the standard jokes of ancient Athens was that of the simpleton who, with the intent of selling his house, carried about a brick as a specimen. In this and the following chapter I propose to follow his example, and, for the purpose of giving my reader a correct notion of the structure displayed in the stratified portion of the earth's crust, to select therefrom a single formation whose details will connect together the subjects discussed in the previous pages. And in so doing it will, I trust, be found that what was ludicrous in the hands of the Greek becomes sober sense in those of the geologist. The "brick," then, which I would humbly present to the thoughtful consideration of the reader as really a specimen of the house of which it forms a part, has been termed the "Carboniferous System," and consists of a series of stratified rocks sometimes

nearly 15,000 feet thick. The plants and animals found in these strata have been already described somewhat in detail, and we have turned aside to look at the processes whereby such masses of sedimentary rock came to be accumulated. But we shall probably better understand the habits of the animals and the general aspect of the vegetation, as well as the agencies at work in depositing vast beds of mineral matter, if we take a coal-field and analyse it stratum by stratum, marking as we go their varied and ever-changing character, and the corresponding diversity of the included organic remains. Such an examination will bring before us some of the more striking and important laws of geological research, and while of use to the young observer, may be not without some share of interest to the general reader. Before beginning, however, let me endeavour to illustrate the principles that will guide us by a simple though hypothetical story.

Suppose the bed of the Firth of Forth were raised above the level of the sea and covered over with verdure, and that, in ignorance of the previous topography of the locality, a mason were to excavate on the lately-born land the foundation for a dwelling-house. Immediately below the grass he would come upon layers of hardened mud containing oyster-beds, with detached valves of cockles, mussels, fish-bones, and perhaps the tooth of an anchor or the timber of some old herring-boat. Now, if he were gifted with but ordinary intelligence, what would he at once conclude from these remains? Plainly, that the spot on which he stood had once been the bed of the sea. And if in place of appearing as dry mud and sand these deposits had got hardened into shale and sandstone, and the shells, too, had become hard and stony, this would not alter his convictions. He would still assert positively that he stood upon an old sea-bottom. And suppose further, that all this were far away from any sea, still such a circumstance could make no change in his opinion; he would rightly assert that

the place of sea and land might vary, and that the ocean's being now many miles distant could be no argument against the waves having once rolled over the site of the intended dwelling-house. Let us further imagine that he continues his trench, and in sinking deeper comes to a bed of dark peat with snail-shells and bones of sheep, deer, and oxen. What will he infer from these? Clearly that they represent an old land-surface, once covered with vegetation and browsed over by ruminant animals, and that this old land-surface has at some distant period been submerged beneath the sea. Suppose, moreover, that below the peat there were a thin bed of reeds and rushes intermingled with the mouldering remains of fresh-water shells. He would in that case infer that before the formation of the peat the locality was occupied by a lake.

Putting now all these deductions together, our mason would have evolved a very interesting history. He would have ascertained that in a bygone age the spot on which he stood was the site of a lake, tenanted by delicate shells and fringed with reeds and rushes, where the coot and the mallard may have reared their young; that in process of time the vegetation gained upon the water, choking up the lake, so as gradually to form a soil firm enough to support sheep, deer, and oxen, and yielding shady coverts whither the antlered stag could retire and lay him down to die; that in after years the sea had encroached upon the peat-moss, and oyster-beds begun to form where cattle had been wont to browse; that again the ocean receded, and the land emerged to assume new verdure and receive new inhabitants.

Now, in all this reasoning there is no hypothesis or speculation. The mason proves himself an intelligent, honest fellow, and uses his eyes and his head where many other men would perchance see very little need for the use of either. There can be no setting aside of his story; he can appeal to facts. "There," says he, "is a layer of peat with the rush-stalks and

moss-fibres matted together in the soft brown mouldering substance, exactly as I have seen them a hundred times in the peat-cuttings on the moors, and I cannot but believe that they must both have had the same origin, that is, that they grew in swampy hollows of the land. There, too, lies a stratum of fresh-water shells identical with those that occur in our ponds and marshes. Although mouldering now, they are evidently not fragmentary, but entire and unbroken; some of them are young, others full-grown, and they lie grouped together as in our present lakes. Such shells could only live in fresh water, therefore the spot where I stand must have been at one time a fresh-water lake. There, again," he continues, "is a bed of oysters which cannot have been transported hither, for their valves are together, lying just as they do in our present oyster-beds. This green field, therefore, must have been at one period a muddy sea-bottom."

After this manner and upon this kind of evidence must all inquiries into the past changes of the earth's surface be conducted. And provided only we proceed cautiously, reasoning from positive facts, and striving as far as possible to exhaust what Bacon calls the "negative instances," our deductions possess all the certainty of truth. For in much the same fashion do we derive no small part of our acquaintance with the early history of our own land, as well as with the arts and customs of other nations. The scattered relics turned up by the operations of the farmer—wooden canoes, flint hatchets, gold torques, bronze pots, fragments of pottery, and rusty coins—all have their bearing upon the annals of the country, and so clear is the evidence which they read out that an eminent antiquary has divided the early ages of Scotland into three periods, distinguished, from the character of their relics, as the "Stone Period," the "Bronze Period," and the "Iron Period."[1] But

[1] See Dr. Daniel Wilson's deeply interesting work *The Pre-historic Annals of Scotland.*

in such a classification the historian has little to guide him save the nature of the relics themselves. He places the rudest first, and groups the rest in succession, according to the degree of advancement in civilisation which they respectively indicate. And the grouping seems just, though in some cases objects belonging to two of these periods may have been to some extent contemporaneous, just as thatched roofs gave way to tiles, tiles to slates, and slates partly to lead, though at the present day a walk of half an hour in some localities will bring before us specimens of all these styles still in use. If, however, the relics of geological history lay scattered about like those of early Scottish history, all hope of ever attaining to anything like a correct chronology and arrangement would have to be abandoned in despair. In truth, it would then be impossible to conjecture whether any succession of ages preceded man, during which other tribes of plants and animals lived and died, or whether the whole mass of fossiliferous rocks had been accumulated since the human era, or perhaps created just as we find them. But all this uncertainty and confusion has been obviated simply by the fossils being ranged in beds vertically above each other, the oldest at the bottom and the latest at the top. So that if we find in a low cliff along the shore blown sand and broken whelks immediately beneath the vegetable mould, and oyster-valves in a clayey bed three feet below, we pronounce the oysters to have lived before the whelks, and that between their respective lifetimes a sufficient interval must have elapsed to allow three feet of sand, clay, and gravel, to accumulate. What is thus true on the small scale holds equally so on the large. The stratified formations in which organic remains occur are found to be grouped regularly over each other in a settled invariable order. If A be below B in England it will be below B all over the world, and if C be above D at the North Pole it will be so at the South Pole too, and at every locality where the two rocks lie together. This

order of superposition forms one of the grand tests for the age of different rock masses. By means of this simple rule the geologist has been enabled to arrange the different stratified formations, supplying the missing portions of one locality from the more complete series of another, so as to form a chronological table of no small part of our planet's primeval history.

But this is not all. We must attend to the character of the organisms as well as to their order of occurrence. We must distinguish the animal from the vegetable, the terrestrial from the marine, and scrupulously examine the peculiarities of each so as to recognise them again in other strata. By such careful scrutiny we may trace out the successive changes in the physical aspect of a district during past times, viewing in terrestrial plants (when clearly occupying their original site) evidence of an old land-surface; in *cyprides*, *unios*, and *paludinæ*, traces of a former lake; and in corals and marine shells, unmistakable proofs of an ancient sea-bottom. Still further, by marking the specific character of such fossils we obtain a key to the age of many rocks that otherwise would be unintelligible, for it is found that each of the stratified formations, from the oldest upwards, has its own peculiar and characteristic organisms recognisable all over the world. This test of the geological position and age of any fossiliferous rock has a peculiar value, for it can be applied with infallible success where every other fails. The order of superposition is often obscured by dislocations and other causes, and the mineralogical texture of a formation may change entirely in a short space; but if the imbedded fossils remain, we can be at no loss as to the relationship of the rock which contains them. And hence, if in some lone island of the Hebrides, haunted only by the screaming sea-fowl, we find a patch of shale containing ammonites, belemnites, and a host of other shells in large measure identical with those occurring among the clays and limestones of Gloucestershire, we infer that they must all belong to one series and be of the same age; that, as

we know the English beds to form part of a formation called Lias, of which the exact place in the geological scale has been ascertained, so in like manner the Scottish beds must occupy a position in the same series; and that consequently there was a time when the site of Cheltenham and part of the Hebrides lay each beneath a sea which teemed with ammonites, belemnites, and many other mollusca, along, too, with the bulky saurians of the Lias. And yet no study of the surrounding rocks in the northern locality, even if carried on for a thousand years, could ever have thrown one ray of light upon the subject. In an earlier page our grey rounded boulder was introduced to the reader as a mass of sandstone belonging to the Carboniferous group of rocks. How could one be sure of the precise geological age of a loose water-worn block that might have journeyed all round the world? Simply by its included fossils. The calamite, lepidodendron, and stigmaria, revealed the date of the stone as clearly and unmistakably as if we had seen it lifted from its original bed by the lever and crane of the quarryman. These plants are peculiarly characteristic of the Carboniferous strata, and they consequently stamp as undoubtedly of carboniferous age the rock which contains them, whether it be sandstone or conglomerate, limestone or shale, and whether we meet with it among the newly-raised blocks of the quarry, or among the pebbles of the sea-shore. Each geological formation, I repeat, beginning at the oldest known to us, and ending with those that are still forming in our lakes and seas, has its own set of organic remains whereby we can detect it wherever it may chance to occur, from the equator to the poles. Each has its *style*, so to speak, just as we can at once tell whether a drawing represents a Hindoo, Egyptian, Assyrian, Greek, or Gothic temple, simply from the general *style* of the architecture.

Could we but voyage back in time as we can sail forward in space, we should find each of the geological formations not less

clearly defined than are the different nations and countries of the present day.[1] Were the reader suddenly set down in an out-of-the-way street of Paris, he would probably not be long in discovering that he stood on French ground. Or if spirited away in his sleep he should awake on the banks of the Nile, he would soon ascertain himself to be in the land of the Ptolemies. And so if you transported a geologist blindfold into a quarry where ammonites and belemnites abounded, mingled here and there with bones of ichthyosaurs and plesiosaurs, he would tell you at once that the quarry lay among liassic strata. Or if he were placed in a ravine where the rocks on either hand displayed fern-stems, lepidodendra, stigmariæ, and sigillariæ, he would tell you that the surrounding district was one of carboniferous rocks, and that probably at no great distance there might be found smoking engines and dozens of coal-pits. Or could you set him down in some dark night upon a wild coast-line, and show him, perchance by the flare of torch-light, bones and scales of osteolepis, pterichthys, and dipterus, lying on the rocks around, he would tell you that the grim crags which shot up into the gloom were as ancient as the era of the Old Red Sandstone. In any case the character of the rock would signify nothing, nor would he care about the general features of the landscape, though these too become important characteristics in certain cases. Show him but a few recognisable fossils, and you give him, as it were, an "Open Sesame" to which the rocks unfold their gates and reveal a store of wonders yet more varied than those in the cave of Ali Baba.

But though the geological systems stand thus strongly marked off from each other when viewed as a whole, their boundary lines can often be only approximately drawn, thereby reminding us that the divisions are of man's device, and can have had no place in the plans of Him who needs not to chronicle His working by years and ages, but with whom there is no past and no future.

[1] See *ante*, pp. 31, 32, and the Table of Rocks at the end of the volume.

One formation insensibly passes into another just as one nation merges into those around it. There are sometimes gaps, however, between the formations, serving to mark out strongly the limits of each,[1] precisely as intervening seas and mountain-chains serve to mark out the boundaries of different peoples and tribes.

The mineral substances of which these formations consist are comparatively few in number, being chiefly varieties of sandstone, shale, conglomerate, and limestone. One sandstone can often be scarcely distinguished from another, and so also with the other rocks; hence such tests as mineralogical texture supplies can seldom be relied on to determine the age of rocks. We can prove, for example, that a series of limestones in England may be identical in age with a set of sandstones in Sweden, and with a group of shales in America, because they all contain the same or representative genera and species of organic remains. They occupy the same position in the geological scale; that is, the animals whose fossilized remains lie buried in these rocks were all living at the same time, while lime was gathering at the sea-bottom over the site of part of England, and sand was being thrown down upon a portion of what is now Sweden, and mud was accumulating over a submerged area of America. In such cases the differences of mineralogical character go for nothing in determining the age of the rocks; we have to rely solely on the embedded fossils, and on the order of superposition.

Keeping in view, then, that the formations into which the

[1] Such cases, however, are probably merely local, and may have originated from some features in the ancient physical geography of the districts where they occur. For instance, it has always been thought that palæozoic ages were marked off by a strong line of demarcation from succeeding secondary times. But the gap which occurs in England, France, and Germany, is being slowly filled up from the evidence furnished by other countries, and we shall probably find in the end that the Permian dovetailed with the Trias as closely as the Silurian with the Old Red, or the Lias with the Oolite. In truth, the longer we study the past history of our planet the less do we see of hiatus and chasm and sharp clearly defined boundary line; while the doctrine of a uniform system of laws and arrangements in the physical world, first philosophically propounded in the immortal "Principles" of Sir Charles Lyell, is ever receiving fresh confirmation.

geologist has grouped the stratified portion of the earth's crust have a settled and invariable order of occurrence, that each of them contains its own peculiar and characteristic group of organic remains whereby it can be recognised in any part of the world, and that such remains form often the sole test at once of the geologic age and of the origin of the rocks wherein they lie, we may return to the plan above proposed and endeavour to understand the structure of a coal-field. For this purpose it may be well to select one of the northern coal-fields of Britain, since these perhaps display a greater variety in their organic contents, and bear evidence of more diversified changes in their mode of formation than can be seen in those of the south. The strata that compose the coal-basin of Mid-Lothian will probably best suit our purpose, as they are free from the disturbing effects of those igneous intrusions which play so important a part among similar rocks to the north and west.

The Mid-Lothian coal-field comprises a mass of stratified beds of sandstone, shale, coal, ironstone, and limestone, the united depth of the whole being above 3000 feet. By reference to the annexed Table it will be seen that the lowest beds of the section are chiefly sandstones and shales, extending downwards to an unknown depth, without any coal that can be profitably worked. These under-strata form the Lower Carboniferous group. Above them comes a middle zone in which the characteristic beds are of limestone, comprising the middle portion or Mountain Limestone of the Scottish Carboniferous rocks. The third and highest subdivision forms the Upper Carboniferous group or true Coal Measures, and constitutes the whole of what is properly the Mid-Lothian coal-field. For the sake of noting some of the remarkable changes exhibited in the character of the rocks, it may be well to begin our survey among the upper beds of the under group. Let us take as our base the famous limestone of Burdiehouse, and work our way upward through the four thousand feet of strata that lie piled above it.

VERTICAL SECTION OF THE MID-LOTHIAN COAL-FIELD.

UPPER CARBONIFEROUS OR COAL-MEASURES.	**Flat Coal Group.** (Above 1000 feet.)	A series of sandstones, shales, and fire-clays, with interbedded seams of coal occupying the central area of Mid-Lothian coal-field.
	Roslyn Sandstone Group. (About 1500 feet.)	A great series of sandstones and shales with three seams of marine limestone (marked here by dotted lines), With the exception of one or two thin seams it contains no coal, and serves in this way to mark off the coal-bearing beds above from the still richer coal-bearing beds below.
	Edge Coal Group. (800-900 feet.)	A group of sandstones and shales similar to those at the top, and like them abounding in coal seams, some of which are thick and valuable.
CARBONIFEROUS LIMESTONE	**Roman Camp Limestones.** (150-200 feet.)	A set of marine limestones intercalated with sandstones, shales, and a few seams of coal.
LOWER CARBONIFEROUS.	Burdiehouse Limestone. (27 feet.) Thickness of Lower Carboniferous Rocks unknown, but probably greater than that of the upper.	Sandstones and shales extending to an unknown depth, often with seams of dull-grey compact limestone, rarely of coal. The beds become very red towards the base, and wholly devoid of fossils.

The Burdiehouse limestone is twenty-seven feet thick, of a yellowish or bluish-grey colour, very compact, splintery, and often fissile in structure, with a finely striped and laminated appearance, which probably indicates a slow and tranquil origin. It is crowded with fossils, every fragment when taken up showing its seed-cone, fern-stem, fish-scale, or minute *cyprides.* All the plants seem to belong to terrestrial species, and have a broken and often a macerated look. Manifestly they never grew where we now find their remains ; they must have come drifting down from swamp, or jungle, or hill-side. And so we come to know that during the later ages of the Lower Carboniferous period, there lay somewhere in the neighbourhood of Burdiehouse a land clothed with ferns and club-mosses, and through whose swampy hollows there spread a network of stigmariæ, while sigillariæ waved their fronds high overhead. From what has been said on a previous page we may infer that the climate of the old land was moist and equable like that of New Zealand, nourishing a prolific growth of ferns and other plants comparatively low in the botanical scale. The scenery of the vegetation displayed perhaps no great variety of outline, but exhibited rather an endless succession of the same graceful forms.

But the limestone presents us with other remains than merely those of terrestrial plants. It displays in abundance the minute dissevered cases of *cypris,* the small crustaceous animal described above. Recent species of this genus inhabit stagnant ponds or the bottoms of gently-flowing rivers, and we hence infer that the ancient species must in like manner have possessed a similar habitat, and consequently that the rocks which preserve their remains must have been deposited in fresh (or, perhaps, brackish) water. Tried by this test the Burdiehouse limestone must be regarded as a lacustrine, or more probably a fluviatile formation, which gathered slowly on an undisturbed bottom swarming with crustaceans and plentifully covered with leaves,

branches, rootlets, and other fragments of terrestrial plants brought down by streams from the adjoining land. Thus the inferences drawn from the numerous plants, and from the countless multitude of cypris-cases, come to be mutually corroborative. The former tell us of some neighbouring forest-covered country; the latter lead us, as it were, into its river-mouths, whence we can descry the waving woods on either side.

Still we have not exhausted all the fossil remains of the Burdiehouse rocks. Mingled among the stems of ferns and lepidodendra, and the scattered valves of the cyprides, lie the scales, teeth, and bones, of several large ganoidal fishes, along with entire specimens of the smaller genera. The scales of holoptychius are especially abundant, often crowded together by dozens, and probably not far out of the arrangement they had when grouped on the body of the living animal. Detached teeth of the same fish also frequently occur along with disjointed internal bones. The remains of the contemporary megalichthys likewise abound, more particularly the scales, which have a fine nut-brown colour, and dot the surface of the rock with their bright glittering enamel. Several other smaller ganoids may be met with, especially a small and elegant species of Palæoniscus (*P. Robisoni*), and one of Eurynotus, a fish remarkable for the great size of its dorsal fin. Not uncommon, too, are the ichthyodorulites of a gigantic placoid—the *Gyracanthus formosus*—with all their delicately-fretted ornament and a peculiar crystalline glistening surface when broken across, whereby the smallest fragment can be easily distinguished from any other bone in the limestone. Such are the ichthyic remains of the Burdiehouse beds; what deductions can be legitimately drawn from them?

As before, we must have recourse to the analogy of living nature. The existing ganoidal fishes chiefly inhabit lakes and rivers, especially near the confluence of the latter with the ocean. They feed on the decaying matter brought down from

the land, or on the minute crustacea that swarm upon the river-bottom. If, as seems probable, the ancient ganoids had habits similar to those of their present representatives, then the rocks wherein their remains occur abundantly may have originated on river-bottoms, and such may have been the case at Burdiehouse. So that here again we have corroborative evidence of the fluviatile origin of the limestone in question. But besides the remains of ganoidal fishes there occur the defensive spines of placoids. Now, the placoids are emphatically marine fishes, and the sole living representative of the most ancient genera of this order is the Port-Jackson shark, that haunts the seas round Australia. The ichthyodorulites of Burdiehouse, therefore, if we would apply analogy consistently, must be regarded as the relics of marine species. And this conclusion, too, will be found in entire harmony with those already obtained, for if we are right in assuming the Burdiehouse strata to have originated at a river-bottom, particularly near the sea, we may expect to find the remains of marine predaceous fishes imbedded in the sediment that gathered there, just as the teeth of the shark may be preserved among the mud forming in the upper reaches of many British estuaries, seeing that not a few instances are known where that fish has been stranded on such shores as those of the higher parts of the Firth of Forth. These Burdiehouse ichthyodorulites give positive proof that the limestone could not have originated in a lake, and the only explanation left is that of a river-bottom.

But it may perhaps be objected that, after all, these fish-remains are for the most part fragmentary, and may consequently be drifted specimens, so that no conclusion as to the source of the rock can be based on their occurrence there. The imbedded land-plants confessedly came from some distance, why may not the same have been the case with the bones and scales of the river-haunting ganoid fishes? And, indeed, did we regard these fish-bones and scales merely in themselves, the argument

might not perhaps be very easily answered, although the great numbers and perfect outline of the bones, teeth, and scales, afford pretty strong evidence that the owners lived and died in the locality where their remains are found. But there is a curious kind of evidence to be gleaned from the rocks around them whereby this objection can be at once set aside. In the limestone itself, and especially in some of the shales above, there occur vast numbers of small oblong coprolitic concretions of a dirty yellow or brown colour, full of scales and fragments of bone. There can be no doubt that these are the excremental remains of predaceous animals, while their great number and perfect preservation assure us that they could not have been drifted from a distance, but must rather have been deposited on the spot where we now find them. And thus we conclude that the site of Burdiehouse must have been a favourite haunt of these bone-covered fishes; that the bulkier forms, armed with pointed teeth or barbed-spines, preyed upon their humbler congeners, while these in turn may have fed on the cyprides that swarmed by millions at the bottom of the estuary. I have often detected in these coprolites the peculiarly-sculptured scales of the palæoniscus. These graceful little animals must, therefore, have died that their lordlier brethren might dine.

On a survey, then, of the whole evidence from fossils, we are led to conclude that the Burdiehouse limestone was slowly elaborated at the bottom of an estuary, into which the remains of terrestrial plants were drifted from the land, while bone-covered fishes haunted the waters, and into these busy scenes huge sharks ascended from the sea to share in the decaying putrescent matter ever brought down from the interior.

The upper part of the limestone is shaly and argillaceous, and rests below a series of shales and thin sandstones. If the question were asked, what caused the change from limestone to shale, from the deposition of a calcareous to that of a muddy sediment, several answers might be given. The most probable

seems to be the following. The limestone on weathered surfaces displays the mouldering casts of cypris-cases sometimes in such abundance as to show that the rock must be largely made up of them. The cyprides of the present day probably cast their shells annually; the integuments thus thrown off forming under favourable circumstances a thin mouldering calcareous marl at the bottom of the pond or marsh, along with the decaying shells of *paludina*, *planorbis*, *limnea*, or other fresh-water molluscs. We may conceive the Burdiehouse limestone to have had a similar origin. The cyprides, inhabiting water that contained little argillaceous matter, must have propagated by myriads, and during a long period of repose, in which the conditions of land and sea, and the directions of tidal currents and river-courses, appear not to have greatly varied in the neighbourhood of Burdiehouse, the calcareous exuviæ of these minute animals, along perhaps with the remains of other estuarine or fluviatile organisms,[1] would form each year a scarce appreciable stratum, until by slow aggregation a bed twenty-seven feet deep was elaborated. Each successive annual layer would hardly settle down more perceptibly or more rapidly than "the flickering dust that mottles the floor of some old haunted chamber."

At last, however, this condition of things came to be modified. The direction of the river channel along some part of its course had varied, or some analogous change had taken place, so that muddy sediment transported from the land sank down amid the cyprides at the bottom. In circumstances so uncon-

[1] Though I have never observed molluscan remains in the limestone of Burdiehouse, they are abundant twelve miles to the west, in the equivalent strata around Mid-Calder, one little gastropod being especially plentiful near the base of the calcareous rock in a seam known to the quarrymen as the "Buckie fake." I have not met with specimens sufficiently perfect for identification, the hard splintery nature of the rock seldom allowing anything but a cross-section to be seen save on weathered specimens, where the general contour of the shells has sometimes reminded me of *Paludina multiformis* grouped together in a recent fresh-water marl. In the shales above the Burdiehouse limestone, Dr Hibbert states he found a *unio* (?), called by him *U. nuciformis*.—*Trans. Roy. Soc. Edin.* vol. xiii. p. 245.

genial these tiny denizens of the estuary diminished in numbers until the silt and sand came down so rapidly and in such abundance that they eventually died out. Alluvial matter still darkened the water and covered the river-bottom, enveloping now the fronds of a delicate fern that had waved along the margin of some sequestered lake far inland, anon a seed-cone that had been shaken by the breeze from the spiky branches of some tall club-moss. Among these muddy beds occur numerous coprolites and fish-scales, along with cypris-cases and a few shells of unio (?), showing that though the cyprides were decreasing, the water still presented the old estuary conditions and still swarmed with life.

Eventually there came other changes in the direction or rapidity of river currents, and the accumulations of mud and silt were succeeded by a long protracted deposition of yellow sand, now forming the sandstone of Straiton. It enclosed many stems of stigmaria, lepidodendron, &c., and in certain limited areas these plants matted together in such quantities that their remains now form thin irregular seams of coal. It would appear, therefore, that notwithstanding these changes in the matter transported and deposited at the locality in question, the estuary character of the locality remained essentially the same. The sand was at length replaced by fresh accumulations of mud and sandy silt, which went to form the beds of shale and shaly sandstone now found above the Straiton rock.

When in the course of many long centuries a depth of strata amounting to fully 300 feet had been amassed, the area of Mid-Lothian underwent a total change. Owing to a depression of the earth's crust, that seems to have been general over the whole of central Scotland, the estuary in which the Burdiehouse limestone and superincumbent strata were deposited became open sea. As the evidence of this change rests solely on the character of the imbedded organic remains, we shall pursue our induction by examining the beds somewhat in detail.

Rather more than 300 feet above the limestone of Burdiehouse there occurs in the Mid-Lothian coal-field a series of shales and seams of limestone. The former are sometimes black and hard, sometimes bluish-grey, soft, and frequently imbedding the remains of several genera of mollusca and other organic remains. The limestones vary considerably in the thickness and general aspect of their several seams, some being highly crystallized and about two or three feet in depth, others dull, compact, and ranging up to twenty and thirty feet thick. The shales and limestones are intercalated with and sometimes pass into each other, through the gradations of shaly limestone and calcareous shales. The whole series may measure 150 to 200 feet, resting on the Straiton sandstone below, and passing upwards into the under part of the coal-bearing strata of Mid-Lothian known as the *Edge series.* These limestones form the northern *marine* equivalents of the mountain limestone of England, while the sandstones and shales on which they rest, including the Burdiehouse beds and all the Lower Carboniferous group, must probably be regarded as *estuarine* equivalents of the same formation. That is to say, while marine limestones were accumulating over the site of central England, sandstone, shale, and drifted plants, were slowly gathering in a wide estuary over what is now central Scotland, and only at the close of the period did marine limestones form simultaneously at both localities.

In examining these Mid-Lothian beds we are struck at once with the great dissimilarity that obtains between their organic remains and those of the underlying strata. All the land-plants disappear—ferns, lepidodendra, sigillariæ, and stigmariæ. The cyprides, too, no longer occur, though the shales seem, at a first glance, to differ in no respect from those underneath, in some of which the cypris-cases were seen to abound. Neither can we detect the glittering scales and teeth that stood out in such strong relief upon the rocks below. Yet the fossils are

scarcely less numerous than they were in the lower beds. Nay, in some of the limestones they lie so crowded together that the rock seems entirely made up of them. Plainly such a total renovation of organic life points to some equally extensive change of a physical kind. Let us examine for a little some of the fossil remains occurring in the mountain limestone series of Mid-Lothian, and read off, if we can, the revolutions which they chronicle.

The neighbourhood of Edinburgh affords many facilities for the study of these rocks. They can be seen, for instance, at many points along the ridge of the Roman Camp Hill, near Dalkeith, exposed in the operations of quarrying. That ridge is formed by what is known technically as an anticlinal axis (Fig. 32); in other words, the lower beds of the coal-measures

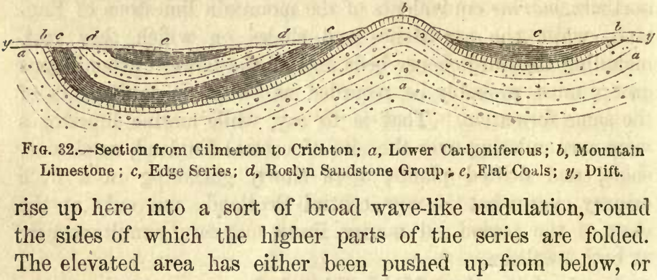


FIG. 32.—Section from Gilmerton to Crichton; *a*, Lower Carboniferous; *b*, Mountain Limestone; *c*, Edge Series; *d*, Roslyn Sandstone Group; *e*, Flat Coals; *y*, Drift.

rise up here into a sort of broad wave-like undulation, round the sides of which the higher parts of the series are folded. The elevated area has either been pushed up from below, or the more level country around has subsided into two trough-like hollows, so that now the strata, which geologically speaking are lowest, come to occupy the highest ground in the district. Seated on some of the opener spots of this woody eminence the observer has a noble prospect on which to expatiate. The ground around him is rich in historic associations, and links itself to many a varied page in the annals of Scotland. The hill on which he rests is crowned by the mouldering mounds of what tradition reports to have been a Roman

station, but which may perhaps belong to a still earlier era. A few hundred yards north rise the wooded slopes of Carberry Hill, where the hapless Mary surrendered to her rebel lords, and whence she was led into her own capital amid the insults of an infuriate rabble. Northward, too, lies the fatal field of Pinkie, and eastward the less deadly but not less decisive field of Prestonpans. To the west the eye can mark the grey smoke of the Scottish metropolis, with its dusky towers and its lion-shaped hill, and then the blue waving outline of the Pentlands that sweep away south and lose themselves among the distant hills which girdle in the coal-basin of Edinburgh and Haddington. The course of the Esk—that *fabulosus amnis*—passes by many a time-honoured spot, from Habbie's Howe and the scene of the Gentle Shepherd down by the haunted scenery of Roslyn, the cliffs of Hawthornden, the grounds of Newbattle, and the old Roman station of Inveresk. East, west, and south, the broad expanse of green field and clustering wood swells upward to the distant hills that encircle the landscape with a wavy line of softest blue. Northward the eye rests on the Firth of Forth with its solitary sails, bounded by the bosky heights of Fife, and opening outwards by the May Island and the Bass Rock into the far-off hazy ocean. On every side objects of historic interest lie crowded together, about which many pleasant volumes have been and might still be written. If the observer be a lover of geological science he will find an examination of the structure of the hill to impart an additional interest to the scene. From the wide panorama of hill and dale, river and sea, with all its battle-fields, castles, and abbeys, and all its memories of the olden time, let him turn into one of the quarries that indent the flanks of the hill, and try to decipher there the records of a still older history. An hour or two thus spent will pass swiftly and pleasantly away, and on quitting the quarry he will have gained a new light in which to look on the landscape that lies spread out below.

The mountain limestone of Mid-Lothian consists, as has been mentioned, of several seams interbedded with black and calcareous shales. The quarries on Roman Camp Hill have been opened in several of the thickest of these seams. Let us enter one of the excavations. A vertical face of rock forms the background, overhung above by long dangling tufts of withered grass, and washed below by a pool of water having that milky green tint peculiar to old lime-quarries. The lowest rock visible is a dull grey limestone with a yellowish weathered surface. Above it rests a mass of hard yellow calcareous shale, known to the workmen as "bands." This rock is worthless as a source of lime, nor from its irregular laminations and shivery structure has it much value in any other way. A few inches of surface-soil form the upper part of the section. It requires but a glance over the weathered surface of the limestone to mark that the rock abounds in fossils. Of these by far the most numerous are the joints of the stone-lily, for the most part of small size, and when broken across, with their minute central apertures, looking like so many fractured stems of tobacco-pipes. Other organisms also occur, such as a small delicately-plaited productus, a larger and more boldly-ribbed spirifer, a small cyathophyllum or cup-coral, and the fragile interlacing meshes of one of the net-like bryozoa—the fenestella. Of rarer occurrence are the whorled shells called bellerophon, the long chambered shells of orthoceratites, and the grooved tapering shells of pinnæ. Many of the same fossils can be detected in the beds above, which thus evidently all form part of one series with the rock below. What, then, were the circumstances under which these strata originated?

The answer to such a question is not far to seek. The corals and crinoids are exclusively marine families, and so any stratum in which their remains occur must have had a submarine origin. It matters not in this case though the specimens be fragmentary, showing a broken and drifted appearance.

For even supposing that they did not live at the spot where their petrified relics are now exhumed by the operations of the quarryman, granting that they were drifted from a distance, still they could only have been drifted from one part of the sea-bottom to another. The state of keeping of the specimen often tells vastly on the value of its evidence when it belongs to a land or fresh-water tribe. Thus, in one of the limestones of West-Lothian I have found a black carbonized stem of sigillaria. Now, the sigillaria was a land-plant as much as any of our hazels or willows, and where the evidence from the associated organisms coincides, furnishes its own testimony as to the origin of the rock which imbeds its remains. But the stem in question was a mere fragment, and showed moreover a worn macerated surface. Such a fossil had evidently no value as a test of the origin of the limestone, which might have been elaborated either in an inland lake or in open sea. That it had really a marine origin, and that the sigillaria actually was, as it seemed to have been, a drifted plant, I ascertained beyond a doubt by detecting on the same slab hundreds of encrinal stems along with the shells, and thin, delicate, silvery spines of productus. Thus, then, the organisms of the land may be carried into the sea, and in dealing with their fossilized remains in the deposits of former ages we must be very careful in the use of evidence derived from fragmentary and drifted specimens. But no such caution is needed in regard to the productions of the sea. If they be fragmentary and drifted, we may believe they were rolled about by tides and currents previous to their final entombment; but still they remain as good a test as ever of the marine character of the rock in which they occur.

The fossils of Roman Camp Hill are not drifted specimens. They must have lived and died where the quarryman now finds them. We recognise them as all unequivocally marine; corals,

[1] The exceptional instance, of the accumulation on the land of blown sand imbedding the broken remains of marine shells, needs only to be noticed here.

crinoids, and brachiopodous molluscs, are all clearly the denizens of the sea, and hence we conclude that they mark the site of an ancient ocean. The snail-shells that swarm about the fruit-trees of our orchards not more unmistakably indicate a land-surface than do these petrified relics evidence an old sea-bottom. We can argue, too, from the crowded way in which they lie grouped together, that life must have been prolific in these primeval waters. Every fragment of the rock shows its dozens, nay, hundreds, of stone-lily joints, disjointed indeed, yet easily recognisable. They must have swarmed as thickly along the floor of the sea as the strong-stemmed tangle that darkens the bottom of many a picturesque bay along our western coasts, yet with a gracefulness of outline such as none of our larger sea-weeds can boast. Less numerous but not less markedly *in situ* are the shells of productus and spirifer, the former with its finely-striated surface fresh as if the creature had died but yesterday, while the slender spines with which it was armed lie strewed around. In short, the whole suite of organisms points to a period of tranquil deposition in a sea of probably no great depth, where the lower forms of the animal kingdom flourished in abundance, contributing by their calcareous secretions to form continuous layers of limestone.

Such a condition of things finds a parallel in many parts of the globe at the present day. Thus, the shores of the islands of the Pacific are white with fine calcareous mud, that results from the action of breakers on the surrounding coral-reefs. This mud, enveloping fragments of coral, shells, sea-weed, drift-wood, and other extraneous substances, hardens on exposure, and becomes eventually a limestone, travertine, or calc-sinter. We may believe that the same process goes on out at sea, around the edges of atolls or circular coral-reefs, and that the sediment thus thrown down will enclose any zoophytes or molluscan remains that may lie at the sea-bottom, along perhaps with *fuci*, and occasional water-logged fragments of wood that have

been drifted from land. Along the shores of Guadaloupe a bed of this calcareous silt has formed since America was colonized by man, for it has been found to contain fragments of pottery, arrow-heads, and other articles of human workmanship.[1] The same rock has yielded, besides, the partially-petrified bones of several human skeletons, one of which, though without the head, forms a prominent object among the fossil treasures of the British Museum. The rock in which these remains are embedded is described as harder than statuary marble, notwithstanding its recent origin. By supposing the same process to be carried on over a large area and for a long period, we may see how a continuous stratum of limestone could be elaborated, full of fossil relics of corals, molluscs, and other marine productions. And in some such way, we may be permitted to believe, the seams of limestone on Roman Camp Hill were accumulated. The billows of that old carboniferous ocean may not have sent up their white surf against the margin of snowy coral-reefs, but the currents below did their work of demolition as effectually, and by sweeping through the submarine groves of stone-lilies and cup-corals, as the night winds of autumn sweep athwart the heavy-laden fields, would prostrate many a full-grown stem and scatter its loosened joints among the thickening lime that covered the bottom. Stone-lily, cup-coral, net-coral, productus, spirifer, pinna, nautilus, orthoceratite, all would eventually be entombed amid the decaying remains of their congeners, and thus produce a slowly-increasing seam of limestone.

We still linger in the old quarry on Roman Camp Hill, but the day draws rapidly to a close, and the long level beams of the setting sun lighten up the higher grounds with a golden flush, while the valley below lies deep in shade. The rays fall brightly on the abrupt face of limestone at the further end of the quarry, every prominence standing out in bold relief, and

[1] Lyell's *Manual of Elementary Geology*, p. 121. Fifth edition.

casting its shadow far behind. Our eye, in passing over the sunlit rock, can detect the fractured joint of many an encrinite glancing in the light; along, too, with the strongly defined outlines of some of the lesser and more abundant molluscs—spirifers or producti. Some of them, sorely effaced by the rains, have begun to yield a scanty nestling place for creeping fibres of moss; others yet bare, afford a rest to the *Vanessa* whereon to spread its wings in the mellow sunset ere flitting homewards among the dewy herbage. The bushes overhead scarcely rustle in the light-breathing air that comes fitfully across the land, and the long grass nods dreamily on the margin of the pool below. There rests a calm stillness on all the nearer landscape, and the distant ground blends away into the shades of evening. The scene, in short, has about it that solemn impressive repose which irresistibly arrests the fancy, and sets it to dress up into fantastic shapes the massive clouds that float in the western sky, to picture grim forms amid the misty shadows of the valley, or to dwell half dreaming upon the memories of the past, that come crowding through the mind in quick succession. Our labours among the fossils of the old quarry, however, enable fancy to draw her stores from another source. We muse on these petrified relics, gilded by the last rays of the setting sun, when slowly, like a dissolving view, sunset and herbage melt away, and the bottom of the old carboniferous ocean lies before us with its corals and shells and stone-lilies, stretching out their quivering arms, or expanding and contracting their flower-like petals amid a scene of ceaseless animation and activity. Geology delights in contrasts, and assuredly the contrast presented to us this evening between the present and the past of Roman Camp Hill, will not rank among the least striking of those which she has to reveal. There is now spread over us the blue sky, richly hung with tinted clouds, and melodious with the evening songs of the lark, the blackbird, and the thrush. Not less surely did a wide expanse of sea during the Carboniferous era

roll over the hill on which we stand. And yonder silvery moon that mounts up amid the violet twilight of the east, has witnessed each scene and all the countless changes that have intervened between them. The same pale light that now begins to steal through the woods and athwart the fields, must have streamed down upon that old sea and illumined its green depths. Oceans and continents, islands and lakes, hills and valleys, have come and gone with all their successive races of living things, and that same planet has marked them all. She has seen, too, as but a thing of yesterday, the appearance of man upon the scene, with all the successive centuries that have elapsed since then. Truly the "goddess of the silver bow" would have a strange story to tell us could we interrogate her about the past. But the days of Endymion have gone by, and she now no longer visits in a personal form the seat of beings who gaze at her crescent orb and daringly pronounce it a scene of blasted ruin and desolation.

CHAPTER XI.

Intercalation of coal seams among mountain limestone beds of Mid-Lothian—North Greens seam—Most of our coal seams indicate former land-surfaces—Origin of coal a debated question—Erect fossil trees in coal-measures—Deductions to be drawn therefrom—Difference between the mountain limestone of Scotland and that of England—Coal-bearing character of the northern series — Divisions of the Mid-Lothian coal-field—The Edge coals—Their origin illustrated by the growth of modern deltas—Delta of the Nile—Of the Mississippi—Of the Ganges—Progress of formation of the Edge coals—Scenery of the period like that of modern deltas—Calculations of the time required for the growth of a coal-field—Why of doubtful value—Roslyn Sandstone group—Affords proofs of a general and more rapid subsidence beneath the sea—Its great continuity—Probable origin—Flat coals—Similar in origin to the Edge coals below—Their series not now complete—Recapitulation of the general changes indicated by the Mid-Lothian coal-field.

Among the old quarries of Roman Camp Hill and down the course of several streams in the same county, the limestone beds of the mountain limestone series are seen to be associated with strata of shale, some of which are highly calcareous, and charged with the same organic remains that occur in the limestones. Such shaly intercalations mark as before the transport and deposition of muddy sediment around and above the corals and stone-lilies of the sea-bottom. All these beds must undoubtedly be regarded as marine. But there occur, besides, seams of sandstone and black partially-bituminous shale, with layers of coal and fire-clay. To this singular intermixture it may be well to advert more particularly, since it forms one of the distinguishing features of these northern rocks, as contrasted with those of central and south-western England, and more especially since it will lead us to mark again the value of fossil remains as evidence of the ancient changes of land and sea.

The southern part of Mid-Lothian consists of a broad heathy moorland, that slopes northward into the more cultivated country, and swells upward to the south into the series of undulating ridges that form the Moorfoot Hills. It is traversed by several streams which rise high among the pasture grounds of the south, and flow some into the valley of the Esk, and thence into the sea at Musselburgh; others past the ancient fortalices of Borthwick and Crichton, and so by the valley of the Tyne into the sea at Tyningham. In their upper course they traverse a broad belt of the mountain limestone that stretches across this part of the country from east to west, and dips away north under the coal-field. Where the streams have been able to cut through the thick mantle of heath, sand, gravel, and clay, by which these higher grounds are covered, we sometimes obtain a complete section of the strata displayed in regular sequence along the bottom of the channels. Thus, one of the rivulets that trickles slowly through the swampy ground of Middleton Muir, on approaching the line of limestone begins to descend more rapidly, and has excavated its course through several feet of the rock below. The limestones are well exposed along each side of the stream, forming in some places steep walls tapestried with moss and overhung with scraggy furze, and offering to the student an instructive series of sections. Near the farm of Esperston, where the stream flows through a narrow secluded valley, the limestones form a floor which the water in the course of centuries has worn smooth, so that the rock with its included encrinal stems and shells, polished by the ceaseless flow of the current, shows like a sheet of variegated marble. At one point on the side of the water-course the observer may notice a low ledge of rock jutting out for a short way along the edge of the stream. The upper part is a hard compact limestone, full of small crinoidal joints. The bed underneath it has been greatly eroded by the rivulet, but enough remains to show that the stratum is one of coal. It rests upon the

series of limestones and sandstones seen in the upper part of the water-course, and is surmounted by the thick limestones of Arniston and Middleton. A similar seam nineteen inches thick has been worked among the limestone about three miles to the west at Fountain. The same bed occurs among the quarries on Roman Camp Hill already mentioned, and I have seen an equivalent stratum intercalated among sheets of cup-corals and stone-lilies on the shore at Aberlady, where the waves have laid open perhaps the finest section of Carboniferous limestone strata in Scotland. In West-Lothian, too, the same intercalation of coal-seams among the mountain limestone beds can be seen in many places. Thus, in the bed of the River Almond, near Blackburn, the following section is laid bare :—

Calcareous shale.
Limestone (marine), eight feet.
Calcareous shale, with *spirifers*, &c.
Coal, six to eight inches.
Fire-clay.
Sandstone.

A short way further down the stream another bed of limestone occurs with several seams of coal below it, one of them attaining a thickness of six feet.

In addition to the thin seam at Esperston, the Mid-Lothian field contains several others. Of these by much the most important is that known as the North Greens Seam. It varies in thickness from only a few inches to fully 5 feet, and has been extensively worked for the *parrot* or gas-coal which it contains. It rests upon a pavement of shale, sometimes of fire-clay, and occurs about midway between two thick marine limestones, being from 80 to 90 feet distant from each. I have laid open many a block of the parrot-coal at the pit mouth, and marked the well-defined outlines of the stigmaria covered with a yellowish efflorescence of iron pyrites, like gilded figures

upon a black velvet ground. The plants lie with their divergent rootlets spread out regularly along the stem like teeth on the back of a comb, thus seeming to indicate no hurried agglomeration by some tidal wave or turbid river, but rather a slow and tranquil deposition.

The fossils of the coal-seams consist for the most part of the plants above described, which we saw to belong to *terrestrial species.* But the reader will now understand that in dealing with organic remains we cannot infer, because a certain stratum contains nothing but land-plants, that it must necessarily by consequence be a land-formation. For we have seen that the plants of the Burdiehouse limestone, though all terrestrial, gave no support to the idea that the rock had originated on land. In all such cases regard must be had not only to the nature of the imbedded organisms, but their condition and mode of occurrence, and to the character of those associated with them. Especial care must be taken to distinguish what has been transported from what is *in situ*, otherwise, by attending only to one part of the evidence, we shall miss the import of the whole, and altogether misinterpret the records which we seek to decipher.

For years the subject of the origin of coal formed one of the many battle-fields on which geologists delighted to break lances. They ranged themselves under two banners, the "drift"-theory men and the "growth"-theory men, the former maintaining strenuously that coal was simply vegetation transported from the land and deposited in large troughs at river-mouths or sea-bottoms, the latter as eagerly contending that the vegetation had not been drifted, but grew on the very locality where its remains are now exhumed. Neither party lacked plausible arguments in support of its doctrines. The "drift" combatants stoutly affirmed it to be contrary to all experience that a land-surface should be so oscillating as their opponents required, that in short it was absurd to hold each coal-seam as marking

a period of elevation, for there were often dozens of seams in as many yards of strata, some of them scarcely an inch thick, and yet, according to the "growth" theory, each would have required for its accumulation a special uplifting of the land above the sea-level. These and many other difficulties were thought to be triumphantly overcome by the hypothesis of transport and deposition. The vegetation borne down by some ancient Mississippi would collect in vast rafts, and these becoming water-logged would sink to the bottom, where, by getting eventually covered over with silt and sand, they would in process of time be chemically altered into coal. This explanation was, however, vigorously resisted by the opposite side. They alleged that the "drift" theory could account neither for the wide extent of coal-seams nor for their remarkable persistency in thickness. If the vegetation had really been hurried out to sea by river-action, it seemed natural to expect that the coal-seams should occur in sporadic patches of very unequal thicknesses, according as the drifted plants had been more densely or more loosely packed. But this was found not to be the case in point of fact. The coal-seams were ascertained to be generally singularly continuous, and to retain for the most part a pretty uniform thickness over considerable areas. And what was still more worthy of note, they were, as a whole, markedly free from extraneous matter, such as sand and mud. Where these impurities did occur, it was usually in the form of intercalated seams or partings, often quite as regular and extensive as the coal itself. Had the vegetation, therefore, been transported into the sea, it could hardly fail to get mixed up with the fine impalpable mud which, like that of the Ganges or Mississippi, might have discoloured the ocean for leagues from the river-mouth, and settled down as a thickening stratum at the sea-bottom. And many other arguments, derived from the nature and arrangement of the strata interbedded among the coal-seams, were urged to prove

that the latter had originated from vegetation which grew on the spot.

The warfare seems now pretty nearly at an end, and as often happens in such cases, it has been found that each party was to some extent in the right and to some extent in the wrong. It has been ascertained that some coal-seams must have originated from the deposition of drift-wood in the mud and ooze of the sea-bottom, while others undoubtedly arose from the decay and entombment of vegetation in swampy plains of the land. That the latter mode of formation has been the usual one in most of our coal-fields has been generally acknowledged since Sir William Logan's announcement that each coal-seam, for the most part, rests upon a bed of fire-clay, which, with its embedded roots, marks the site of an ancient soil. This fact has been abundantly confirmed in every part of this country, and indeed wherever an extended series of coal-seams has been examined. Not only have the underlying fire-clays been found, but in not a few instances erect stems of trees, passing down through the coal-seam and spreading out their divergent roots in the clay below, exactly as they must have done when they flourished green and luxuriant in the

Fig. 33.—Section from Cape Breton coal-field, showing four planes of vertical stems, and seven ancient soils with their covering of vegetation.

a, sandstones; *b*, shales; *c*, coal; *d*, fire-clays; *e*, arenaceous shales.

times of the Carboniferous system. This was especially the case in the Parkfield Colliery, Wolverhampton, where seventy-three trunks were laid bare in the space of about a quarter of an acre, each with its roots attached. The same appearance was observed some years ago in the Dalkeith coal-field, where a group of erect trees was encountered covering a space of several square yards. Some instructive sections of such fossil-forests are given by Mr. Brown from the Cape Breton coal-field.[1] In one of them (Fig. 33) no fewer than four planes occur, each supporting its group of erect stems. Now, no one can glance over this and the other sections illustrative of the same paper, or the descriptions given by Sir Charles Lyell and others of the Nova Scotian coal-field, without being compelled to admit that the trees in question grew just where their upright stems can still be seen, and consequently that the accompanying coal-seams originated not from vegetation drifted by river-action, but from vegetation that grew upon the spot. And though erect stems do not exist in every coal-field, we seldom fail to detect the not less important occurrence of the fire-clays and hardened shales that support the coal-seams and prove by their embedded rootlets their identity with ancient soils. Thus we arrive at the inference that while in certain localities coal-seams have resulted from drifted vegetable matter, they have nevertheless for the most part been formed from plants that flourished where the collier now excavates, amid damp and dripping caverns, their carbonized remains.

Applying, then, this deduction to the strata occurring on the horizon of the mountain limestone in Mid-Lothian, we are led to believe that the North Greens coal-seam marks the site of a former land-surface. It shows no vertical stems, but has all

[1] *Quart. Jour. Geol. Soc.* vol. vi. pp. 120, 130. The cut given above (Fig. 33) is taken from one of these sections as modified by the late Sir Henry de la Beche (*Geological Observer*, p. 582). In the original the beds are inclined at a considerable angle, but for the sake of clearness they are here reduced to horizontality.

the other accompaniments of an ordinary seam, such as the underlying fire-clay and shale, with their included stigmariæ. And this conclusion has more than ordinary interest, for if it be true, we have evidence of a terrestrial formation among strata unequivocally marine; in other words, we see proofs either of an elevation or a filling-up[1] of the sea-bottom carried slowly on until land-plants grew up in matted swamps where once there swarmed corals and encrinites, and then of a gradual subsidence, so that marine organisms flourished again in abundance over the site of the submerged vegetation. It is not insisted that each of the thin coal-seams among the limestone strata marks a former terrestrial area. Some of them may possibly have resulted from the transport and deposition of plants borne from the land. Yet there are others of wide extent resting upon beds of fire-clay which contains stigmaria rootlets, &c. These I cannot but regard as the remains of plants that grew upon the spot. And so, while we recognise in the beds of limestone undoubted evidence of a former sea-bottom, I am persuaded we must equally admit that at least several of the coal-seams bear fair evidence of a former land-surface, scarcely raised above the sea-level indeed, but nourishing nevertheless a thickly matted vegetation. In this way we shall see the mountain limestone series of the Lothians to be not a purely marine formation, but one partly marine and partly deltoid, showing in the succession of its strata proofs of a gradual submergence, interrupted by movements of elevation, so that the area which at one period formed the ocean-bed became at a later time low

[1] If it be correct to set down the North Greens coal-seam as really representing a terrestrial surface, that is, of course, a flat delta or plain scarcely raised above the sea-level, we must, I suspect, call in the aid of a slight elevatory process, or else hold that the depth of the sea at the locality where the lower limestone was forming did not exceed 80 or 90 feet, and may have been considerably less, and that this space came to be eventually filled up by the detritus of the river. But the wide extent and sometimes the great thickness of the limestone beds seem to indicate a greater depth, and thus favour the idea of an elevation of the sea-bottom to form the North Greens coal-seam.

delta-land, and after continuing perhaps for ages to stretch out its verdant surface beneath the open sky, sank again amid the corals of a wide-spread sea.

Now this condition of things differs entirely from what is presented by the Mountain Limestone group of England. That formation, when typically developed, attains a thickness of from 1000 to 2000 feet, and gives rise to that green hilly kind of scenery whence it has derived its name. It is unequivocally a marine deposit, since it abounds in corals, echinoderms, brachiopodous molluscs, and other productions of the deep. Northward, however, it undergoes a gradual change, getting greatly thinner, and split up by a series of intercalations of shale and sandstone. This alteration goes on until, on the border-land between the two countries, the massive limestone of Derbyshire has dwindled down into a series of thin beds, often widely separated by intervening strata, which contain many seams of coal. After crossing the Silurian district, and descending the northern slopes of the Lammermuir Hills, we get into the Carboniferous system again, and find its limestone series still farther diminished. With this decrease of marine formations, we can detect an augmentation of coal-bearing strata. Thus the Berwickshire coal-field lies in this lower set of beds, far under the coal-measures of Newcastle. In the Lothians, too, as has been shown, coal is extensively worked in the same series, and these seams also find their representatives in Fife and Lanarkshire. The gradual change from the kind of strata found on the horizon of the Burdiehouse limestone, to those occurring on the horizon of the Mountain limestone, indicates, as we saw, a gradual change of the conditions of deposition; and the nature of this alteration is shown by the difference in the character of the imbedded fossils. The passage of the massive Derbyshire limestone into the thin limestones and coal-bearing sandstones of the north, as decidedly marks another change in the relative position of sea and land. The former

was a succession in time, the latter was one in space, but the mode of reasoning remains the same for both. In the former case, we saw estuarine strata passing upward into others wholly marine, and the order of superposition told us that the locality was first an estuary, and then slowly became open sea. In the latter case, we see marine beds not succeeded by estuarine strata, but becoming estuarine strata themselves. The thick limestones gradually thin out horizontally into a great series of sandstones and shales, with interbedded coal-seams, so that what bears evidence of a deep sea at the one end, gives proof of a muddy and sandy delta at the other. In other words, during the ages represented by what we call the Mountain Limestone, the central and south-western portions of England lay far below a wide breadth of ocean, and nourished a luxuriant crop of stone-lilies, mingled with the other denizens of the deep, while the Border district, and the whole of central Scotland, exhibited all the conditions of a vast delta, sometimes spreading out as broad verdant jungles, anon showing only scattered irregular groups of low, bare mud-banks and sand-spits, which at other times disappeared altogether beneath the dun discoloured waves. Now the reader will not fail to mark that this curious and interesting fact in the past history of our country, is ascertained solely from a comparison of fossil remains. The stone-lilies and shells of Derbyshire, and the lepidodendra and land-plants of the Lothians, form our sole basis of evidence, and we may rest on them with as perfect certainty as if they were so many duly attested documents deposited among the archives of our State-Paper Office.

In our survey of the coal-field of Mid-Lothian, we have passed from the Lower Carboniferous estuary beds of Burdiehouse to the Middle Carboniferous marine beds of Roman Camp Hill, and their associated terrestrial strata,—the coal-seams and fire-clays. We come now, in our upward progress, to the Upper Carboniferous group, or Coal-measures proper.[1] These

[1] These terms—Lower, Middle, and Upper Carboniferous, are used for want of others,

strata rest immediately upon the limestones, and attain a depth here of over three thousand feet. They consist of a great series of sandstones, shales, coals, and fire-clays, that vary in thickness from less than an inch to many feet, or even yards. The coal-seams are especially variable, many of them existing as mere films of carbonaceous matter; others varying up to a depth of fourteen feet. There are from fifty to sixty that exceed a foot, but the average thickness throughout the whole series is about three and a half feet.[1] They are nearly all underlaid by fire-clay or shale, and very generally have a roof of the latter material.

By referring to the diagram of this coal-field, given above at p. 196, the reader will notice that the series is divisible into three groups:—1*st*, and undermost, a considerable depth of coal bearing strata known as the *edge series*, because they lie along the western limits of the coal-basin at a high angle, and sometimes even on edge; 2*d*, A great thickness of sandstones nearly barren of coal, but containing at least three beds of limestone—this may be termed the Roslyn sandstone group; 3*d*, and highest, another series of coal-bearing strata, commonly called the *flat coals*, because they occupy the centre of the basin where the beds repose at a low angle, and are in places quite flat. It will be convenient to keep in mind this threefold division, for it will point us to some important changes in the ancient conditions of this coal-field.

The edge series, which forms the lowest, and of course oldest of the above groups, averages from 800 to 900 feet in thickness. It contains about thirty seams of coal above a foot thick, and many more of less size. They occur irregularly, some lying

and for the sake of clearness. They must not be regarded, however, as equivalent to similar groupings of the English carboniferous rocks, for the Scottish series is probably much older than the greater part of the English, and coeval, to a considerable extent, with the mountain limestone and millstone grit of the latter country.

[1] See Milne on Mid-Lothian Coal-field. *Trans. Royal Soc. Edin.* vol. xiv. p. 256, whence the above details are taken.

only a few inches apart, others from eighty to ninety feet, the intervening space being occupied by sandstone or shale.

Now as each coal-seam, with its associated underclay, appears to mark a former land surface, it will follow that there must be as many old land surfaces in this series of strata as there are such coal-seams, and that for every intervening mass of sandstone or shale, the area of vegetation must have been submerged. This conclusion would have been violently resisted by the supporters of the "drift" theory. They would have roundly asserted that such an unsteady surface was a mere supposition to suit a hypothesis, unsupported by fact, and contrary to the analogy of existing nature; and they would not perhaps have hesitated to maintain, that such an oscillating land could be little fitted to nourish so rich and luxuriant a vegetation as that of the Carboniferous period. But it will not be difficult to show that our conclusion, so far from being contrary to analogy, is amply borne out by the processes of existing nature, and that its opponents, and even its original asserters, failed to perceive that what it demands is not a rapidly oscillating crust, but one as steady and uniform as that of many of the least disturbed countries at the present day; and that we do not require to call in the aid of a special elevation and submergence for every coal-seam, but that for the most part the hypothesis of a steady sinking of the area of a coal-field, interrupted perhaps by occasional elevatory movements, along with an active and constant deposition of sediment by the varying currents of a large river, is sufficient, if not thoroughly to explain, at least to throw great light upon the origin of those enormous masses of strata composing our present coal-basins. The oft-recurring variations in the nature of the strata that form our coal-measures, sandstones alternating with shales, these again with coals and fire-clays, together also with the terrestrial origin of the coal-seams, and the occasional presence of true marine organisms, make it evident that, to obtain any modern analogue to such a

condition of things, we must examine those localities where large bodies of fresh water, carrying sediment and vegetation from the land, mingle with the sea. Let us then look for a little at the operations now in progress at the mouths of the larger rivers, and mark how far they elucidate the structure and history of a coal-field.

"Egypt is the gift of the Nile." Such was the conclusion arrived at by one of the most diligent observers of ancient Greece —the venerable Herodotus.[1] He sailed up the river marking all the leading features in its scenery, and noting the more apparent evidences of ancient physical changes. His remarks on these subjects form one of the earliest specimens of scientific reasoning that have come down to us, and are remarkable for their correctness and the truly inductive mode of thought which they evince. Modern travellers have amply confirmed the opinions of the father of history, and we now know that but for its central river, Egypt would be a vast dreary expanse of arid sand like the neighbouring deserts of Lybia. The Nile, by annually inundating the country, deposits over it a stratum of rich loam, and thus not only waters the land, but continually renews the soil. The sediment in this way brought down has gradually encroached upon the waters of the Mediterranean, being heaped up at the river mouth into shifting sand-banks, islets, and great tracts of low, swampy ground, slightly raised above the sea-level. Through this series of silting deposits, the river sends a number of branches, often winding in labyrinthine convolutions, and ever changing their course, by wearing away the silt at one place, and throwing it down at another. The area traversed by the

[1] *Euterpe*, 5.—His words are very emphatic. "To one of ordinary intelligence, who has not heard of it before, but sees it, Egypt is manifestly land acquired by the inhabitants, and a gift from the river—δῶρον τοῦ ποταμοῦ." The 10th and 12th chapters of the same book deserve especial study for the admirable inductive style in which the historian compares the phenomena observable in Egypt with what were well known as the results of river action in other lands. The passages might be quoted word for word in the most rigid scientific argument of any modern geologist.

mouths of the Nile was called by the Greeks the Delta, from its similarity in form to the Greek letter, and the name has since been given to all such fluviatile deposits, whether they have this general form or not.

The sediment annually deposited by the Nile varies in thickness in different years. The mean thickness of the annual layers at Cairo has been calculated not to exceed that of a sheet of thin pasteboard, so that "a stratum of two or three feet must represent the accumulation of a thousand years."[1] Such thin laminæ must resemble greatly some of the more fissile shales in the Carboniferous system, which were, perhaps, formed by as slow a process, and in their aggregate depth probably took many thousand years to accumulate. But those fluviatile depositions of the Nile vary little in kind, for when cut through they are found regularly stratified down to their base, which rests upon the great underlying sand. They show us how the argillaceous seams of the coal-measures may have originated; but the diversity of character in these Carboniferous rocks indicates a more varied kind of sediment, and probably more rapid and active transporting currents. A closer analogy to such a condition of things meets us on the shores of the New World.

The Mississippi, so magnificent in all its proportions, has raised a delta which covers a tract of about 14,000 square miles, equal to almost half the area of Ireland. The lower parts of this delta are formed of low, shifting banks, traversed by innumerable streams that diverge from the main river, and alternately throw down and remove vast quantities of earthy sediment, intermingled with rafts of drift-wood. These swamps are covered with a rank growth of long grass and reeds, and for about six months of the year are more or less submerged below the waters of the river, while liable at the same time to continual inundation and encroachment from the sea. The higher parts of the delta, though also subject to a similar periodical

[1] Lyell's *Principles*, p. 262.

submergence, nourish a more luxuriant vegetation. Vast tracts of level sandy soil are densely overgrown with pine, which is used extensively for making pitch. Large districts of the swampy ground are covered with willows, poplars, and thickets of the deciduous cypress, an elegant tree that rises more than 100 feet above the soil. When in hot seasons these swamps get dried up, "pits are burnt into the ground many feet deep, or as far down as the fire can descend without meeting with water, and it is then found that scarcely any residuum or earthy matter is left. At the bottom of all these 'cypress swamps' a bed of clay is found, with roots of the tall cypress, just as the underclays of the coal are filled with stigmaria."[1] In this way a thick accumulation of vegetable matter goes on forming for years, until either the river changes its course, and inundating the swamp gradually covers it over with sand and mud, or until, owing to oscillations of the earth's crust, the district is either permanently submerged, so as to be silted over, or elevated to nourish a new and different kind of vegetation.

That such changes have taken place in the past history of the river we have several interesting proofs. Thus, owing to the great earthquakes of 1811, 1812, an area of more than 2000 square miles was permanently submerged.[2] Since then it has gone under the name of the "Sunk Country;" and Sir Charles Lyell, who visited the locality in 1846, that is, thirty-four years afterwards, tells us that he saw innumerable submerged trees, some erect, others prostrate. Now, it is easy to see how such an area may, when the climate suits, become the receptacle of vast accumulations of peat, which, by pressure and chemical action, will ultimately pass into coal. If we suppose the submergence carried on more rapidly at some periods, the plants might have been unable to keep pace with the ever-increasing inroads of sand and mud. In such cases the layer of vegetation

[1] Lyell's *Elements*, p. 386.

[2] See Sir Charles Lyell's *Second Visit to United States*, chap. xxxiii.

would become eventually entombed beneath succeeding deposits of earthy matter. Were the amount of sediment thus thrown down sufficient in the end to counteract the downward motion of the earth's crust, and so raise the bottom of the river or lake to the level of the water, vegetation would spring up afresh and clothe the new raised surface as densely as in former years. This alternation, according as the amount of sinking or the amount of sediment predominated, might go on for thousands of years, until a series of strata many thousand feet thick were accumulated, and tranquilly carried down bed after bed below the level of the waters.

It is interesting to know that the case supposed here has actually been realized in the delta of the Ganges. Some years ago an Artesian well was attempted to be made near Calcutta, and the auger was sunk to a depth of 481 feet.[1] The material passed through consisted of sand, clay, and nodules of argillaceous limestone, and at various depths, from 50 to 380 feet, several seams of decaying wood and peat were found, along with bones of various animals, such as deer and fresh-water tortoises, and fragments of lacustrine shells. Each of these vegetable layers evidently formed at one time a forest-covered swamp like those of the surrounding delta at the present day; and hence it follows, that during the accumulation of the Gangetic delta, the ground in that locality must have undergone a depression of more than 300 feet, and that this sinking has been interrupted by slight elevations, or by periods when the ground remained stationary, so as to admit of a dense and prolonged growth of vegetation, at successive intervals, upon the swampy flats and shifting islands. The general appearance of these old forests is pretty well shown by the mangrove swamps along the mouths of the river. These trees flourish in dense jungles on the banks, and extend even below high water mark, being covered in places by shell fish. So that were these maritime

[1] See Lyell's *Principles*, p. 280.

parts of the delta inundated by the ocean, and buried beneath a mass of mud and silt, the peaty layer that would be formed would display trunks of trees still occupying their original erect position, and spreading out their roots in the clay below, exactly as the sigillaria is found to do in the coal-seams of the carboniferous rocks, while clustered round the carbonized stems, or scattered among the decayed leaves and branches, there might be detected limpets and barnacles (as lingulæ and pectens occur in the coal-seams), showing, by their mode of occurrence, that they lived and died upon the spot.

If my reader will now suppose this sand of the Indian river to be hardened into sandstone, the mud in like manner compressed into shale, and the peat beds chemically altered into coal, can he fail to perceive the striking analogy between the section thus displayed and those already given from the Mid-Lothian and Cape Breton coal-fields? The differences between the ancient and modern strata are not in kind but in degree. The Scottish series reaches to more than six times the thickness of the Indian one, and the coal-seams in the one exceed in individual thickness the peat-beds in the other. We must remember, however, that the climate of Hindustan is not remarkably favourable to the accumulation of vegetable matter, the heat being so great that the plants decay almost as rapidly as they grow. And it should likewise be borne in mind, that were the conditions of subsidence and of the gradual accumulation of sedimentary matter to continue even in the same ratio as heretofore, the Ganges might, in the course of ages, heap up a series of stratified sands, clays, and peat-beds, many thousand feet in thickness, and many thousand square miles in extent, rivalling, or perhaps surpassing in depth, the largest coal-field in the world. The parallelism between this delta and an ordinary coal-field holds singularly close, not merely as regards the nature of the stratified deposits. The alluvial plain of Bengal has undergone a process of subsidence to an unknown depth, whereby successive areas of terrestrial vegetation have been carried down

to be entombed beneath fluviatile sand and mud. It is likewise subject to the more sudden operation of earthquakes, whereby large tracts of country become permanently altered, and changes are effected on the direction, rapidity, and detritus of the streams. It is, moreover, liable to wide-spread inroads of the sea, which sometimes covers cultivated districts to a depth of several feet, laying waste the fields and destroying the inhabitants. These and other features help us to understand the origin of such vast masses of sedimentary strata as those of our coal-fields, where terrestrial, fluviatile, and marine remains alternate in rapid sequence, or sometimes occur together.

The origin of the constant succession of coal seams, sandstones, and shales, of the Edge series may be thus accounted for. The area of Mid-Lothian formed part of a great delta, which, like that of the Ganges, was undergoing a gradual subsidence during the Carboniferous era. The rate of this movement probably varied at different times, and might even be occasionally interrupted by short periods of elevation. When the ever-increasing accumulations of silt brought down by the river reached or nearly reached the surface of the water, they would become the site of wide tracts of swampy vegetation that flourished for hundreds or thousands of years. Eventually, however, these jungles, invaded by the changing currents of the river, were buried beneath a thick deposit of fluviatile sediment, or more probably the vegetation might become unable to keep pace with an accelerated rate of submergence, and the forests would then be tranquilly carried down beneath the water, and soon covered over with sand and mud. The detrital matter might in like manner continue to be deposited over the sunk forest for many years, perhaps centuries, until the muddy bottom again reached the surface, and once more waved green with sigillariæ, calamites, and lepidodendra. Another long interval might here elapse, in which a thick bed of vegetable matter might accumulate, much after the manner

of the formation of peat among the bogs and mosses of our own country. The periodical inundations of the river probably gave rise to wide marshes and lagoons, often tenanted by lacustrine shells, and thickly overgrown with aquatic vegetation. The decaying plants decomposed the red ochreous matter with which the water was charged, and re-deposited it among the mud and rotting leaves at the bottom as a carbonate of iron. Such ferruginous accumulations, often entombing fern-stems and other plants, with scales and teeth of ganoidal fishes, sometimes *conulariæ* and *lingulæ*, and, in certain localities, whole acres and miles of fresh-water shells, are known now as our *clay-band* and *black-band ironstones.* We can easily conceive that, in shallower parts of the lagoons, a dense growth of marshy plants might spring up, preventing any deposition of iron, and when the whole came to be covered over with later accumulations of sand or mud, the deeper parts of the old lake would be covered with a seam of ironstone, and the shallower portions would display a bed of coal. In some such way we may account for the frequent passage of ironstone into coal, and coal into ironstone in many of our coal-fields. If undisturbed by the ever changing currents of the river, these wide expanses of marsh and lake might continue for many long years, the constant evaporation being counterbalanced by continual supplies of water from the main stream. Eventually, however, owing perhaps to another period of more rapid submergence, the water gained the ascendency, and once more rolled over prostrate stems and matted thickets of ferns, that sank slowly down beneath a deepening sheet of sand and mud. Often, too, the sea must have flooded, perhaps for years, the flat delta-lands, carrying with it its own productions, such as the lingulæ and cardiniæ, which we find among the coal seams. And thus the process went on during the long ages of the Carboniferous system. Forest after forest spread its continuous mantle of green athwart the low swampy lands of that old delta, and each in succession foundered amid the muddy waters, now of

the ocean and now of the river, that strewed over its site a rich detritus which went to form the soil of new jungles and forests.

The Edge series measures from 800 to 900 feet in depth, so that the depression must have been carried on till the forest that once grew nearly on the sea-level had sunk 800 feet below it. This process was undoubtedly a very slow and tranquil one. Yet geologists used to regard these frequent changes of sedimentary matter as so many proofs of repeated catastrophic submergences, when the ocean came rolling over the land, prostrating forests, uprooting the hugest trees, and leaving the scattered bones and scales of fishes amid vast accumulations of mud and sand, where but lately there had bloomed a luxuriant vegetation. But the sober and diligent student of geologic fact will read in these rocks no such record of cataclysms. He will see in them evidences of the same gradual and sure operation which marks the processes of Nature at the present day. He will note how during a tranquil and probably imperceptible submergence of the river-bottom, forest after forest sprang up, flourished perhaps for ages, and eventually settled down beneath the waters of the river and sometimes of the ocean, amid ever increasing accumulations of mud and sand. Musing on these ancient changes he will be lost in wonder at the immense duration of the period during which they were in progress; and he will try in some measure to realize the features of their scenery. He will picture the delta with its ever-varying islets and sand-banks, its lakes and submerged forests, its leafless trunks peering above the water and sticking along the shoaling mud, and its crowded jungles that cover every drier spot. He will cast his eyes to where the delta opens out into the ocean, and mark how the waves encroach upon the mud-banks, cutting away what the river has piled up, and washing the roots of gigantic trees that wave their green coronal of fronds above, and overshadow the rippling of the green sea below. He will try to thread the windings of the stately river through brakes

of ferns and calamites, and banks richly hung with tree-ferns and sigillariæ, and then upward through dark shaggy pine-woods, silent and gloomy, with the water creeping lazily through the shade or dashing in white cascades over dripping rocks, and onward still, far away among the distant hills till the fountain-head of the great stream is reached, gushing from the splintered sides of some lone rock, or pouring perchance out of the glimmering caverns of some massive glacier high amid the regions of perpetual snow.

Many attempts have been made to estimate the amount of time which some of our coal-fields may have required for their accumulation. But so large a number of conjectural elements must necessarily enter into such calculations, that the results come to be of very doubtful value. By estimating the amount of sediment annually transported by such rivers as the Ganges or Mississippi, we may ascertain how long a mass of similar sedimentary strata would take to form under similar conditions. And if our calculation had to do merely with such detrital accumulations, we might hope to arrive at some approach to accuracy. But besides these sedimentary strata, the formation of which must have been wholly analogous to that of similar deposits at the present day, we have to deal with the problems suggested by the coal-seams. We know nothing of the climate of the Carboniferous period save what may be conjectured from the analogy of existing climates; and in a question regarding the accumulation of decaying vegetable matter climate is a subject of the first importance. We are ignorant, too, of the rate of growth peculiar to the carboniferous flora; and even if we hold that it was probably rapid, the process of decay may have been equally speedy, and so a forest might go on shooting up fresh trees as the old ones rotted away, yet at the end of a thousand years there might be a scarcely greater thickness of vegetable matter on the ground than at the commencement. A seam of coal two feet thick might thus represent, say the

accumulation of a hundred years, and another of exactly the same thickness might stand as the accumulation of a thousand years. Until we know more of the vegetation and climate of the coal period, the thickness of a coal-seam can hardly be held as a certain guide to the lapse of time required for its formation.

For the sake of illustration, let me take the following fragment of a coal-measure section :—

Shale, . .	20	feet.
Coal, . .	4	,,
Fire-clay, . .	6	,,
Sandstone, .	40	,,

Beginning at the bottom, we may compute the period of the forty feet of sandstone variously, according to the river selected as the type of a transporting agent. Tried by the standard of the Nile, all other conditions being similar, such a deposit would require perhaps not less than 14,000 years ; by that of the Mississippi, 5000 ; and by that of the Ganges, nearly 2000.[1] We come, then, to the superincumbent fire-clay and coal, representing an ancient soil and the forest that grew on it. The occurrence of these seams shows us that the river-bed had become a swampy tract clothed with vegetation ; but who shall say how long it may have continued so ? Like the sunk country of the Mississippi, it may have been submerged, and to some extent cut off from the sediment-transporting channels of the river, and thus, as a vast lake, have nourished a prolific growth of marshy and aquatic plants. If the temperature resembled that

[1] Some observers have pointed to the occurrence of vertical and inclined trunks of trees in the Carboniferous sandstones, and deduced therefrom what has seemed to them a triumphant argument in favour of the rapidity wherewith our coal-fields must have formed. A foundered tree, they say, sank with its heavy-laden roots among the sand at the bottom, its stem pointing up into the water like the snags of the Mississippi, so that the sand must have come rapidly down to entomb the whole before it had time to decay, and thus thirty or forty feet of sediment must have been deposited in a few years, perhaps even months. But this is somewhat like a begging of the question. We have yet to learn how long a water-logged trunk will resist decomposition.

of our own country, the growth of peaty matter, other circumstances being favourable, might be comparatively rapid. If, however, as seems probable, the climate were more warm and humid, giving rise to a more luxuriant vegetation, and at the same time to a more rapid decay, a long interval might have elapsed without adding materially to the thickness of the vegetable accumulations, and the eventual entombment of peaty matter sufficient to consolidate into four feet of coal, might be owing in some measure to the submergence of the swamp beneath the waters of the river, whereby a quantity of detrital matter was deposited that arrested the process of putrefaction, and entombed the thickly matted plants which were growing on the spot at the time. Hence, until we know more of the conditions under which vegetation may accumulate at river-mouths in such a climate as the coal plants are conjectured to have enjoyed, calculations of the amount of time required for the formation of a great series of coal-bearing strata must be regarded as premature. In the present instance, we can but affirm that the growth of the four-foot coal-seam probably occupied many long years, even at the most rapid rate of accumulation known to us. The forest-covered swamp on which the plants grew was eventually invaded by muddy detritus brought down by the river; and during another period of indefinite extent—five hundred years or five thousand years—fine mud continued to settle down over the foundered forest, hardening eventually into twenty feet of shale.

The Edge coals of the Mid-Lothian coal-field are succeeded by a group of sandstones and thin shales, with three or more seams of limestone. This group of strata, which we may call the Roslyn Sandstone Series, reaches a thickness of from 1200 to 1500 feet, and serves as a middle zone to divide the Edge coals below from the Flat coals above. It contains only a few thin laminations of coal, and these chiefly at its upper and under portions. Such a great intercalation of beds, without coal-seams, points,

we might readily conjecture, to some change in the physical conditions of the ancient delta. The nature of this change can be easily made out from an examination of the rocks, and the reader will see that here again we are indebted to fossil remains for the most conclusive and satisfactory evidence of these old physical revolutions.

The absence of coal-seams suffices to indicate that during the formation of the middle group that part of the delta occupying the site of Mid-Lothian was continually submerged, and never rose to the surface so as to allow a covering of vegetation to form upon it.[1] The large beds of sandstone prove a continued transport and deposition of detritus during undisturbed periods of considerable length. The intercalations of shale, pointing to local changes in the currents or other modifying causes, are usually of small thickness and extent, while the sandstone beds sometimes attain a depth of 150 or 200 feet, and extend over wide areas of country. So far these mechanical rocks indicate the deposition of sand and mud under water, but whether at river-mouth or sea-bottom is left uncertain. From the fossil remains, however, we learn that the deposition took place in the sea, but at no great distance from land ; in other words, the area of Mid-Lothian, which, during the accumulation of the edge coals, had been alternately clothed with vegetation and inundated by the river, sank down many fathoms, so that the sea rolled over it and all its submerged forests. The proof is twofold,—first, from the character of the organic remains in the limestones ; and second, from that of those in the sandstones and shales.

In some of the streamlets that flow into the beautifully wooded vale of the Esk, south of Penicuik, these limestones can

[1] Of course, this deduction is founded, as the reader will notice, on the assumption that we have now the series, as it was deposited, and that no peaty swamp or forest was denuded away, and its site occupied by sand and silt. But the assumption is rendered probable from the conditions of formation indicated by the Roslyn group.

be well seen, worn in the water-channel, or crusted over with moss along the banks. Their organisms are singularly abundant, and consist of cyathophylla, encrinites, spirifers, producti, &c., all exclusively marine. In a picturesque brook that falls into the Esk near a saw-mill in the grounds of Penicuik House, I have seen the little cup-corals clustered by dozens on the weathered rock, showing their delicate striated wrinkles in high relief among the scattered valves of productus and innumerable joints of the stone-lily. They were all well preserved, and in their grouping and general appearance differed in no respect from similar organisms in the mountain limestone of Roman Camp Hill. The inference to be drawn from them must accordingly correspond with what has been deduced from the mountain limestone fossils, viz., that they mark the site of a sea-bottom which remained free from mud and sand for considerable periods, during each of which there abounded corals and shells, whose exuviæ went to form several seams of limestone. But that this sea-bottom was at no period very far distant from land, is proved by the drifted plants that occur in the sandstones and shales both below and above, and which often show so little trace of maceration, that we can hardly believe they were carried far, or floated for a long while previous to being enveloped in the sand or mud at the bottom. I have never detected vegetable remains in the limestones themselves, but there seems no reason why they should not be found there.

One of the most remarkable and difficult phenomena presented by these limestones is their great persistency. I have traced them over a large part of Mid-Lothian, from the highly inclined beds at Joppa to the contorted and faulted strata near Carlops. I have found them, too, in many parts of West-Lothian and Stirlingshire, from the sea at Borrowstounness southwards into Lanarkshire. They likewise occur in Fife, and seem to sweep away through Lanark and Ayrshire. The area in which I have found them cannot be much under 700 square

miles, yet they are probably spread over a much greater extent of country. Throughout this region they appear to continue on the whole at pretty much the same vertical distance from each other, and average three or four feet thick each. They vary in number, three being found in parts of Mid-Lothian, in other parts only two. Throughout West-Lothian there seem to be but two seams in the middle or moor-rock series, and the same two seams are found passing over into Perth near Culross. There are differences, too, in the structure and composition of the seams, one running sometimes as a single bed of dull blue limestone, and then gradually splitting up into three layers of a greyer and more earthy texture, with soft shale between them. But making all these abatements, the observer cannot fail to be struck with the general regularity and continuity of these limestones. And the fact becomes all the more remarkable when we consider the great irregularity, and continual intercalations, and repetitions of the strata, both above and below. Marine beds are usually persistent over large areas, especially where extensively developed. As they decrease in thickness, their continuity for the most part lessens, so that the rule is, on the whole, a safe one, the thinner any particular stratum, the less likely are we to trace it to a considerable distance. Yet, not only are these Mid-Lothian limestones thin, but they occur in regular sequence among a set of continually alternating and very irregular beds, and extend over several hundred square miles of country. And this, too, not in a single seam, but in two, three, or even more, so that the difficulty of accounting for such intercalations is proportionately increased.

We have seen above that the area of a delta is often partially submerged below the sea, and that such changes may become of the most marked kind where the country is liable to be depressed by earthquakes. There can accordingly be no difficulty in understanding how the ancient carboniferous delta of Mid-Lothian may have likewise subsided. But the lime-

stones are unmistakable evidence that not only was the area of the delta submerged, but that for a while no sediment was deposited over it, and hence marine animals peculiar to clear water flourished so long and so abundantly as to form by their remains several beds of limestone. Had these beds been merely local we might have regarded them as having been deposited in lagoon-like portions of the delta, shut out from the detrital matter of the river on the one side and open to the sea on the other. But their wide extent and nearly uniform thickness preclude such a supposition. The following explanation appears to me the most probable :—

After the series of the Edge coals had been brought to a close, the coal-fields of Scotland underwent a complete submergence below the sea. This depression was probably very gradual, yet more rapid than that long-continued one which had been going on during the earlier part of the Carboniferous series, and the consequence of this greater rapidity was to prevent the growth of stigmaria swamps or reedy jungles, by keeping the alluvial surface continually sunk to some depth below the water. The amount of subsidence until the deposition of the lowest limestone may not have been great, but even a slight depression would tell vastly on an area of flat delta land. Mud banks would be brought down into the region of waves and surface-currents, and speedily be spread out over the floor of the sea. Forest-covered islands would in like manner be levelled down, and their trees sent drifting seaward or submerged amid the re-formed silt. Thus altered, the delta would sink below the sea, and the sediment borne down by the river would be scattered out over the older deposits as a slowly-forming sheet. By degrees this detrital matter must have been carried less and less farther out to sea ; in other words, the area of deposit or delta must have crept gradually nearer to the land—a result owing partly to the recession of the ancient coast-line, and partly perhaps to a greater amount of depression inland than at the

coast, which would of course lessen the velocity of the streams and cause them to deposit their burden of sediment at higher levels than before. The consequence of this retreat of the delta from the sea would be to purify the water over the site of the old swamps, and render it fitted for the habitation of corals, molluscs, and other marine animals. A medium thus prepared would not be allowed to remain long untenanted, and so we find that it came to be densely peopled with the organisms peculiar to such a station. Stone-lilies, cup-corals, net-like bryozoa, molluscs of many kinds, and large predatory fish, swarmed in these old waters, and their calcareous shells and skeletons are now broken up by the quarryman and the collier as hard compact limestone.

After these animals had lived and died in successive generations, perhaps for thousands of years, the downward movement of the earth's crust seems to have ceased for a while or to have become greatly less. The effect of this would be just to reverse what had been previously done, especially if a slight elevatory movement took place. The streams would in such circumstances descend from the uplifted ground with renewed velocity and transport their detritus to gradually increasing distances. The muddy and sandy sediment thus borne seawards would slowly silt over the coral-banks at the bottom, and in conditions so ungenial the organisms would dwindle down and finally die out. A great thickness of sand and mud would be spread out over their remains so long as the currents from the land continued to carry sediment out to sea, and thus probably originated the sandstones and shales superposed above the lowest limestone.

Eventually the old steady downward movement returned, and with it the corals and stone-lilies. The detritus again sank to the bottom much nearer the land, forming great banks and shoals that choked up the river-mouth. Seaward the water regained its purity, and the bottom once more swarmed

with living things. Another lapse of many thousand years may have here intervened during which the marine exuviæ gathered into another seam of limestone, until again the process of subsidence either ceased for a time, or what is perhaps more probable, became considerably feebler. Detrital matter began to creep seaward as before, and eventually entombed the corallines and crinoids to a great depth. The calcareous bed thus formed is the second limestone, and the superincumbent silt-beds represent the sandstones and shales that rest above it.

In some such way as this does the Roslyn sandstone series appear to have originated. I have indicated what seems to have been the main features in the process, but it was probably a very complex one. There may have been a great many oscillations of level of variable effects, some of them raising the disturbed area to a much greater height at one point than at another. This inequality would of course produce marked effects along a low flat country such as that at the mouth of a great river. New currents would be produced and the direction of old ones changed ; great shoals and banks of silt would be worn down only to be thrown up again at some new point, where another oscillatory movement would expose them afresh to destructive denudation. The variations in the amount of elevation and depression would likewise modify the transport of detritus to the sea, and give rise to a varied and ever-changing sea-bottom. In short, the alternations and variations must have been endless, for to the ordinary multiplied interchanges of a delta we must add those induced by a constant and unequal oscillation of the earth's crust.

The Roslyn sandstone series comes to a close, and passing onward in ascending scale we meet with another great group of coal-bearing strata. They occupy the central area of the Mid-Lothian coal-field, and from their gentle inclination as compared with the lower strata that rise up from under them on either side of the basin, are known as the *Flat Coals.* Their

total thickness—that is to say, all that has escaped denudation—amounts to a thousand feet or more. They consist chiefly of sandstones, shales, ironstones, and fire-clays, with from twenty to twenty-five seams of coal, of which sixteen are thick enough to be worked. Their similarity to the Edge coals below points to a similarity in the conditions of formation. The frequent alternations of sandstone and shale show how the delta gradually pushed outwards again and re-occupied its ancient site above the successive forests of the Edge series and the successive coral-beds of the Roslyn group. The coal-seams indicate the further progress of the detrital accumulations, and the eventual formation of vast swampy flats that nourished a rank growth of stigmariæ, and tracts of drier ground waving with ferns, and shadowed by the spiky foliage of the club-moss and the broader fronds of the tree-fern.

The Flat coals are not succeeded by any other palæozoic strata. Above them stretches the drift already described : sometimes in the form of a stiff blue clay resting on a striated rock-surface ; sometimes as a coarse gravel containing fragments of all the rocks in the neighbourhood ; and sometimes as a fine white sand diagonally laminated, and often showing dark partings of coal-fragments. From the section given above (Fig. 32) at p. 196, the reader will see that as the upper limit of the Flat coals is formed by the drift, a large part of that series may have been borne away by denuding agencies. Had there been even a seam of limestone above them, it would have sufficed to show their true thickness, for we should then have seen, that how much soever had been removed in later times from above the limestone, nothing had been removed from below it ; and so it would mark the true original limit of the series. We cannot now tell how much thicker the upper part of the Mid-Lothian carboniferous system may have been. Probably, during the long ages that intervened between palæozoic and post-tertiary times, many hundred feet were borne away and carried

to other sites, there to grow up into new islands and continents, clothed with other types of verdure, and peopled by other races of animals, and fitted to become, in a long subsequent period, the dwelling-place of man.

In fine, the evidence of these ancient changes in the history of the Mid-Lothian coal-field is derived, as we have seen, from two sets of facts; first, those of a mechanical, and, second, those of an organic kind—the one class explaining and confirming the other. Beginning our investigation at the horizon of the Burdiehouse limestone, we saw the curtain rise slowly from off a wide estuary, in which there gambolled large bone-covered fishes, while huge pine-trees—branchless and bare, seed-cones, fern-fronds, and twigs of club-moss, floated slowly away out to sea. The panorama moved on, and brought before us the ocean-bed of the Roman Camp limestone, with its groves of stone-lilies and bunches of coral; its tiny shells moored to the bottom, or creeping slowly athwart the limy floor, or spreading out their many arms, and rising or sinking at will. This picture passed slowly away, and then came the delta of the Edge coals, with its sand-banks and ever-shifting currents, its stigmaria swamps, and its forest-covered islets. We saw the delta gradually sink beneath the sea, and corals and stone-lilies cluster thick over its submerged area, to form the limestones of the Roslyn group. Again, the mud-bars of the river crept out to sea, and tangled forests waved green as of old, washed by the sea or inundated by the river. How this last period came to a close, we shall probably never know, and have no possible means of conjecturing. We pass at one step from the ancient era of the coal to the comparatively modern one of the drift—from a verdant palæozoic land, to an icy post-tertiary sea. It is like a leap in history from the days of Pericles and Aspasia to those of King Otho, or from the tents of Runnymede to the Crystal Palace of Sydenham.

CHAPTER XII.

Trap-pebbles of the boulder—Thickness of the earth's crust unknown—Not of much consequence to the practical geologist—Interior of the earth in a highly heated condition—Proofs of this—Granite and hypogene rocks—Trap-rocks; their identity with lavas and ashes—Scenery of a trappean country—Subdivisions of the trap-rocks—Intrusive traps—Trap-dykes—Intrusive sheets—Salisbury Crags—Traps of the neighbourhood of Edinburgh—Amorphous masses—Contemporaneous trap-rocks of two kinds—Contemporaneous melted rocks—Tests for their age and origin—Examples from neighbourhood of Edinburgh—Tufas or volcanic ashes—Their structure and origin—Example of contemporaneous trap-rocks—Mode of interpreting them—Volcanoes of Carboniferous times—Conclusion.

In the previous pages, allusion has been made to the trap-pebbles imbedded in the boulder, to the various forms of decay exhibited by granitic and trappean rocks, and to the elevation and depression of the solid crust of the earth. Will the reader bear with me for but a few pages more, while I seek to indicate one or two points of interest in a branch of geology that would abundantly reward a diligent observer? Since the days of Hutton, the investigation of what are called *igneous* rocks has fallen somewhat into the background, and geologists have given themselves, perhaps too exclusively, to the study of organic remains, so that while the palæontology of the British islands has enjoyed an extensive exploration, but little has been done towards the elucidation of our igneous formations and their accompanying phenomena. Much remains to be accomplished, even in those districts usually regarded as in a manner threadbare, and he must be but an indifferent observer who cannot add a few gleanings to the general stock of information upon this branch of British geology.

Many conjectures have been formed, and many theories propounded, as to the nature of the internal parts of our globe. Some have supposed that there is an outer solid film or crust, some ten or twenty miles thick, enveloping a vast ball of intensely heated matter; others have attempted to show that the interior must be nearly solid throughout, with, however, great lakes, or vesicles of gas and melted rock, somewhat after the fashion, we may suppose, of the oil-holes in a Gruyère cheese. But whether the heated material occupy the whole or only parts of the internal area, is not of much consequence to the practical geologist; he is content to believe that it exists, and in sufficient quantity, too, to produce the most momentous changes on the surface of the earth. We see the effects of this subterraneous agent in earthquakes and volcanoes, and the geologist can tell us of similar, as well as of other changes, effected by it during past ages. Granite hills, and mountainous districts of mica-slate and gneiss, bear evidence of what is termed *metamorphism*—a change in the mineral structure of rocks, believed to have taken place through the agency of heat deep in the interior of the earth; for no analogous appearances have been detected in progress at the surface. Such rocks, known as *metamorphic*, or *hypogene*, still form a difficult problem, not likely to be satisfactorily solved until the chemist shall have thoroughly investigated the subject; for it seems likely to be found, after all, that long-continued chemical action, without a very alarming degree of heat, may have produced even the most intense metamorphism. But dropping this part of the subject, in which so much yet remains to be discovered, let us look for a little at another branch of the geologist's evidence, where we meet with no such hampering hypotheses and doubtful conjectures, namely, the *trap*-rocks.

Every one knows that basalt, lava, pumice, scoriæ, and ashes, are the various matters ejected from volcanoes. When these materials are found interstratified among the various geological

formations, they are termed *trap*-rocks,—a name derived from the Swedish *trappa*, a stair, in allusion to the step-like or terraced appearance which they often present. They are of all ages, having been detected in the lower Silurians of Wales, and in the deposits of all subsequent periods up to the volcanic eruptions of the present day; thus evidencing, that from the remotest times there have been Ætnas and Vesuvii slumbering perhaps for ages, and then awakening to lay the surrounding districts in ruins. I have already said that the rocks from which the geologist has to compile his history, are mostly relics of the sea; hence most of the trap-rocks which he meets with in his explorations are the products of submarine eruptions. Far away down among the Silurian rocks, he can trace the floor of a primeval ocean thickly covered with stone-lilies, trilobites, and molluscs, and in following it out he marks how ashes and lapilli, ejected from some submarine orifice, settled down amid the organisms and well-nigh destroyed them, while at other times streams of molten matter were poured out along the sea-bottom, and hardened into masses of solid rock. He sometimes even encounters what seems the vent whence these eruptions proceeded, filled up now by a *boss* or plug of hardened trap, but he never can detect any trace of land. Some of these oceanic volcanoes may, like Graham's Island in the Mediterranean, have raised their tops above water, sending clouds of steam and cinders far and wide through the air, but the waves would eventually wear down the new-born land, and scatter its broken fragments along the floor of the sea. Among the carboniferous rocks of Scotland, however, we meet with a different condition of things. There, too, we can trace out submarine lava-streams, and mark how showers of ashes destroyed the delicate organisms of the deep; but we encounter, besides, undoubted traces of a land, not parched and ruinous as though the igneous forces had laid it waste for ever, but thickly clothed with vegetation of a more luxuriant type than that which clusters

over Vesuvius and Calabria, or lies spread out across the "level plains of fruit-teeming Sicily."[1] We have looked at the plants and animals of the Carboniferous era; its rivers and deltas; its slow elevations and depressions of the ground. It may, perhaps, complete the picture of that ancient period, if we examine, though but briefly, its igneous eruptions, the more especially since these may be regarded as, to a considerable extent, typical of trap-rocks belonging to every age and every country.

Unless when deeply buried beneath drift-sand and clay, trappean regions usually possess scenery of a marked kind. A green undulating country stretches out as far as the eye can reach, diversified here and there with bold abrupt crags and conical hills. The lower grounds show in the winter season their rich brown loam, that waxes green as the spring comes on, and ere summer's close spreads out its heavy crops of golden grain. The higher ridges are for the most part thickly wooded, yet the soil is often scanty, and, among the white stems of the beech, or the matted roots of the fir and the elm, we may not unfrequently see the rock protruding its lichen-crusted face, mottled with mosses and liverworts, while some sluggish runnel collects in stagnant pools, or trickles over the blocks with a thick green scum. Sometimes the hill has never been planted, but stands up now, as it has done for centuries; its western face craggy and precipitous, with bushes of sloe-thorn and furze, and stray saplings of mountain-ash clinging to the crevices, while its eastern slope sinks down into the rolling country around with a green lumpy surface, through which, at many a point, the grey time-stained rock may be seen. The whole district suggests to the fancy a billowy sea, and, as one casts his eye from some commanding hill-top athwart the wide expanse of hill and valley, sweeping away in endless undulations, he is apt to be-

[1] Τῆς καλλικάρπου Σικελίας λευροὺς γύας.—Æsch. *Prom. Vinct.* 369—a passage graphically descriptive of an ancient eruption of Ætna.

think him of some day far back in the past, when the verdant landscape around lay barren and desolate, while the solid earth rocked and heaved in vast ground-swells like a wide tempested ocean. Such is the aspect presented by some of the more trappean regions of Scotland. But the origin of this kind of scenery must be ascribed to the effects of denuding currents in scooping out the softer strata into clefts and valleys, and leaving the harder trap-rocks in prominent relief, rather than to any great inequality of surface produced by the eruption of igneous matter; for we shall find that the throwing out of sheets of lava and showers of volcanic ashes was often a very quiet process after all.

Trap-rocks generally may be variously classified according to the aspect under which we view them. Mineralogically they are *augitic*, when the mineral *augite* enters largely into their composition; *hornblendic*, when the *augite* is replaced by *hornblende;* and *felspathic*, where *felspar* forms the most marked constituent. The first class includes all the dark homogeneous compounds called *basalts;* the second, the hornblendic *greenstones*, or *diorites;* and the third, the *felstones*, *porphyries*, and *tufas*. Geologically, they are *beds* when they are interstratified with the contiguous rocks; and *dykes* or *veins* when they penetrate them like walls, or in an irregular manner. The former class may be either of the same age with the rocks among which they lie, or of a later date, just as in a pile of books the centre one may either have been placed there originally with the rest, or thrust in long afterwards. The latter class must always be later than the rocks which they traverse, for it is plain the rocks must have been in existence before trap-dykes and veins could be shot through them. Hence geologists are accustomed to speak of contemporaneous and subsequent trap-rocks: the one list including all the tufas, and those melted rocks which can be shown to have been erupted during the time when the limestones, sandstones, or shales around them

were forming; the other embracing all the dykes and veins along with those beds of melted rock which have been intruded between the strata. These and other distinctions will be better understood from a few examples collected chiefly from the carboniferous district of central Scotland.

The trap-rocks seen there exhibit a wide range of structure, texture, colour, and general aspect. There are two pretty marked kinds—the augitic or hornblendic, and the felspathic; the former being usually of a more or less crystalline aspect; the latter, commonly dull, and often without any crystals.[1] In the augitic traps, the crystals are sometimes of large size and well-defined, so that the rock could hardly be distinguished at first sight from an ordinary grey granite, while at other times, and not unfrequently even in other portions of the same mass, the stone assumes a black appearance without distinct crystals. The former variety would be called a *greenstone*, the latter a *basalt;* the chief components in either case being felspar and hornblende, or felspar and augite, with a variable admixture of other minerals, the shade of colour varying from a pale blue or leek-green, through the different hues of grey, to a deep velvet black. There are other traps, however, consisting entirely, or nearly so, of felspar, whence they are known as *felstones.* Such rocks enjoy a wide range of colour, some of them being pure white, others of a bluish grey or dingy brown; and they may be seen graduating from a pale yellow, or flesh-colour, to a brick-red or deep purple. When a trap displays distinct disseminated crystals, usually of felspar, it becomes a *porphyry;* when it shows rounded cavities, like those of furnace-slag, it is said to be *vesicular;* and when these globular or almond-shaped cavities are filled with carbonate of lime, chalcedony, or other minerals, the rock forms an *amygdaloid.* Such peculiarities of

[1] This distinction, though a sufficiently safe one in some localities, must not be held as by any means universal in its application, the felspathic traps being often as crystalline in aspect as the augitic, and the augitic, on the other hand, as dull as the felspathic.

structure indicate to some extent the origin of the mass, and may be found in any kind of trap. Thus we have porphyritic greenstones, basalts, or felstones, and the same rocks may be likewise vesicular or amygdaloidal. Some of them, such as many greenstones, display on weathered surfaces that curious spheroidal structure already alluded to ; others are built up into geometric columns.

Such peculiarities of composition and structure form the basis of a mineralogical classification of the igneous rocks, which is of use in working out the geology of a district. The most convenient subdivision for our present purpose, however, is that which proceeds upon the origin and mode of occurrence of the trap-rocks. Viewed thus, they resolve themselves into two great groups, the *intrusive* and *contemporaneous*, both of which contain greenstones, basalts, &c.,—the sole distinction between those of the one class and those of the other, being the relation of age and mode of occurrence which they bear to the surrounding rocks.

I. The *intrusive* traps occur in the form of walls and veins, sometimes in that of flat parallel beds, and often as huge amorphous masses, to which no definite name can be given. But whatever shape they may assume, they generally agree in presenting well-marked features, whereby their origin can be readily ascertained. The rocks through which they pass are more or less hardened, often contorted, and sometimes traversed by innumerable cracks and rents, into some of which the trap has penetrated in the form of veins.

A trap-dyke is a long wall of igneous matter, cutting more or less perpendicularly through the surrounding rocks. Sometimes these dykes attain a breadth of many yards, and may not unfrequently be traced for miles running in a nearly straight line over hill and valley, easily recognisable by a long smooth ridge, with the rock protruding here and there from below where the soil is thin. It is interesting to follow out one of these long ramparts from its beginning to its close, and mark

how undeviatingly it cuts through the rocks. No matter what may be the nature of the stone encountered, hard conglomerate, friable shale, compact limestone, or jointed fissile sandstone, all are broken across, and the right line preserved throughout. Nay, I have seen a still more curious instance of this persistency, where the dyke ran for four miles through a set of mountain limestone and lower coal-measure strata, and several enormous sheets of greenstone and basalt. Even when passing through these traps the dyke remained perfectly distinct, its crystalline structure and external configuration presenting a well-marked contrast with those of the surrounding eminences. Of course it must have been formed after all the rocks through which it passed. The sandstones and shales must have settled down long previously on some estuary bed or sea-bottom ; the corals and shells of the limestones, and the matted plants of the successive coal-seams must have lived and died, perhaps thousands or millions of years before, and their remains have hardened into stone, ere the continuity of the strata was broken across by the long deep wall of greenstone. Trap-dykes are accordingly appropriately termed *intrusive.* They have been intruded among and must always be later than the rocks in which they occur. In tracing out their character, more especially in a trappean district, such as that of Linlithgowshire, where they abound, we soon find other evidence of their intrusive nature. Where they pass through limestone, they sometimes convert it into a white saccharine marble ; shales they bake into a sort of porcelain or burnt pottery ; and sandstones become semi-fused into a hard homogeneous quartz-rock. Nor are the changes confined to the rocks traversed ; the dykes themselves, along their sides, become fine grained and hardened ; occasionally, too, the colour alters from the usual bluish or greenish-grey to black, or to a brick-red, or dull-brown, similar to that of the altered shale and sandstone, of which detached portions may be found adhering to the outer walls of the dyke, or even em-

bedded in its substance. The central portion of the dyke may thus be markedly crystalline, forming what we should call a greenstone, while the outside parts, where the trap comes in contact with the adjacent rocks, are fine grained and homogeneous, so as to become a true basalt. Sometimes, too, these exterior edges are highly vesicular and amygdaloidal, detached fragments closely resembling the slag of an iron-furnace, and occasionally the dyke presents a columnar arrangement, the ends of the hexagonal or polygonal columns abutting against the sandstone or other rock on either side, and losing themselves towards the centre in the general mass of the trap. Where the strata traversed are broken and jointed, the dykes which cut them through may be seen in some places throwing out lateral veins that accommodate themselves to all the irregularities of the fissures. These minor portions exhibit for the most part the same leading features with the parent mass, and the result of the whole is a general baking of the beds, with sometimes not a little contortion, and an amount of irregularity and disturbance, apparent at once to the most inexperienced observer. (See Fig. 34.)

If the reader will verify these statements by actual exploration in the field, he will probably not be long in arriving at the following conclusions: trap-dykes must once have been in a melted state, as is shown by their vesicular cavities and divergent veins; this liquid condition must have been attended with the most intense heat, as may be gathered from the burnt and baked appearance of the contiguous rocks; they have, for the most part, especially where of large size, risen from below along previously-formed dislocations—a circumstance which may be inferred from their persistency in a straight line through beds of very different resisting power, for had the liquid matter forced a way for itself, it would have squirted between the beds along the lines of least resistance, and not directly and for miles across them; and hence, trap-dykes must be regarded not as

themselves the agents in dislocating and contorting a district, but merely as signs of the parent force at work below.

All the features of these trap-dykes here stated may be observed in the central district of Scotland, among rocks of Carboniferous age. But he who would study trap-dykes on the great scale without quitting Britain, should visit some of the more trappean islands of the Hebrides. He will there find them intersecting glen and hill-side, in an intricate network, standing up through the heather like ruined walls, and running often for considerable distances up bald cliff-line, and across precipitous ravine. In some localities, among such limestone districts as that of Strath, detached eminences may be seen with congregated dykes coursing their sides and summits, while the heathy interspaces are cumbered with grey and white protruding blocks of marble, that give to these green knolls the aspect of old time-wasted abbeys with their clustering tombstones. The magnificent sections laid open in these localities by the action of mountain streams, and by the waves of the Atlantic, leave the student of igneous rocks nothing to desire save a long lease of leisure.

Another form frequently assumed by the intrusive traps, is that of wide beds or sheets intercalated with greater or less regularity among stratified rocks (Fig. 34 *b*). They may be regarded as horizontal dykes, the igneous matter, in place of cutting across the strata, having forced a way for itself between them. Viewed in this light they will be found exactly to correspond with ordinary dykes; the rocks on which they rest, and those which lie above them being both altered like those on either side of a dyke or vein. A well-known example of this form of trap is that of Salisbury Crags, where a bed of greenstone twenty to eighty feet thick is intercalated among sandstones, shales, and coarse limestones, belonging to the Lower Carboniferous series. Its under surface presents a remarkably even line, broken at intervals, however, where the truncated ends of sandstone beds pro-

trude up into the greenstone, or where the latter cuts into the sandstone below, occasionally enveloping detached fragments, and sending veins through them. Along the line of contact both rocks undergo a change. The greenstone becomes reddened, finer grained, and of a dull earthy aspect. The sandstones and shales are also red, and excessively hard, the former resembling a quartz rock, and the latter passing into a sort of flinty chert or chalcedony. The sandstones above the trap, where they can be examined, are also found to present the same hardened, baked appearance, the most intense metamorphism being observable in those parts which are completely surrounded by igneous matter. These points were noted many years ago during the famous controversy between the disciples of Hutton and Werner, the former viewing them as demonstrative evidence of the igneous origin of the trap-rock, the latter, on the other hand, professing to see nothing in the section of the Crags at all militating against the theory that the rocks had originated from deposition in water. Many a battle was fought in this locality, and not a few of the trap-dykes and hills possess to the geologist a classic interest, from having been the examples whence some of the best established geological opinions were first deduced. The contest between the Huttonians and Wernerians terminated long ago in the acknowledged victory of the former; Hutton's doctrines are now recognised all over the world. It is interesting, however, to walk over the scenes of the warfare, and mark the very rocks among which it raged, and from the peculiarities of which it took its rise. Basalts and greenstones, sandstones and shales, with all their crumplings and contortions, still stand up as memorials of powerful igneous action, and of physical changes in the primeval past; and they have become to the geologist memorials, too, of changes in the onward progress of his science, where, out of conflicts perhaps yet more tumultuous than those of ancient Nature, there emerged at last the clear demonstrable truth.

In the accompanying section (Fig. 34), the more marked characters of intrusive traps are exhibited. The main mass of igneous rock is the dyke (*d*), rising through a dislocation or fault, which has thrown down the beds on one side several feet below those on the other, as is shown by the interruption of the shale and ironstone beds (*sh*). The dyke gives off two ramifications, one of them cutting across the beds obliquely as a vein (*v*); the other passing along the planes of the shaly layers as a horizontal bed (*b*). The vein, it will be noticed, produces considerable alteration in its progress, carrying up and

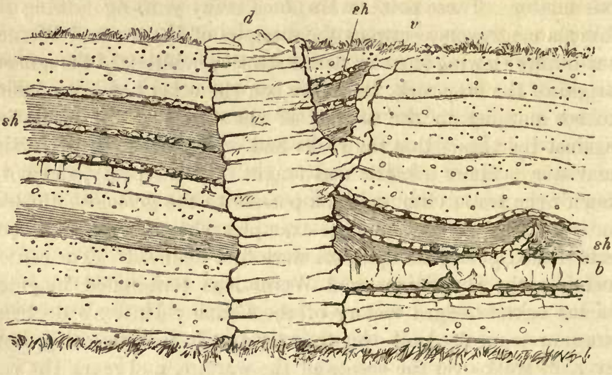


FIG. 34.—Intrusive Trap.

baking a portion of the shale (*sh*), and turning up the edges of the beds on both sides, which get cracked and hardened along the line of contact. The bed runs with some regularity for a short distance through the shales, which show marks of great alteration at their junction with the trap. Its under surface at one point is seen to have involved a portion of the shale which has become in consequence highly metamorphosed, while along the upper surface the bed has sent out a short

irregular vein that twists and otherwise alters the shales above. These circumstances would suffice to show that even though we did not find this bed in connexion with a mass of intrusive trap, it must, nevertheless, have been thrust among previously-formed strata, and could not have been contemporaneous, that is, poured out along the sea-bottom before the shales above it were deposited.

But one other form needs to be mentioned here as characteristic of the Carboniferous intrusive trap-rocks—that of great amorphous masses which cut through the strata irregularly. They have not the wall-like form of dykes, nor do they conform to the line of bedding of the rocks among which they occur. They are sometimes irregular lumps, lying above or among the strata, and probably connected with some vein or dyke below. In other localities they look like the upper ends of vast pillars which may descend into the very depths of Tartarus, as though a great hole had been blown through the crust of the earth, and a column of melted matter had risen to fill the cavity. Such masses are often called *bosses*, and seem not unfrequently to have been the craters of eruption whence great sheets of lava and showers of ashes were ejected far and wide over the neighbourhood. They serve to connect the intrusive traps, whose age is always more or less uncertain, with the bedded traps properly so called, the geological date of which can usually be sufficiently ascertained.

II. The bedded or contemporaneous trap-rocks consist of two well-marked kinds. There are, 1st, the melted rocks, such as greenstones and basalts; and 2d, the tufas and volcanic ashes.

Those of the first-named class differ in no respect from the traps already noticed, so far as regards mineralogical texture, general structure, and appearance. In hand specimens the intrusive and bedded greenstones and basalts cannot be distinguished, nor even when examined in the field and in masses extending over considerable areas is it always possible to say to

which division any particular hill or crag should be assigned. The reason of this resemblance is obvious. Where a trap has either cut through or insinuated itself among rocks of earlier date it is called intrusive, in relation to the rocks so traversed, and of course we cannot be sure to what geological period it should be referred, nor how long an interval may have elapsed between the time when these rocks were forming and the time when the trap was intruded among them. If, however, the igneous rock passed upward through these same strata and then spread out as a flat sheet along the sea-bottom, the part that came to the top would be termed contemporaneous with the deposits going on at the time. Hence it follows that all contemporaneous lava-form trap-rocks are at the same time intrusive as regards the strata passed through in their progress to the surface. If the sheet of melted matter that spread out below the water were in the course of ages worn completely away, along with the strata subsequently piled above it, so as to leave merely a *neck* or dyke filling up the cavity through which the lava rose, we should pronounce the remnant intrusive, and could form no certain conclusion as to its age or as to whether its site had ever been a crater actively at work in throwing out lava and ashes. The sole difference, therefore, between a contemporaneous and an intrusive greenstone is simply this: the former rose through a fissure until it reached the surface, and then rolled out as a flat parallel sheet; the latter may have been erupted from below at the same time, yet, owing to different circumstances, never reached the surface, but spread out among or cut through the strata underneath. And so, when we come to examine in quarries, ravines, and other exposures, the remains of two such eruptions, we soon ascertain the relative age of the former from that of the strata among which it occurs, but as to the date of the latter we are wholly at a loss, for it gives us no clue by which we can show whether it was erupted before or after the other. We can but

compare the mineralogical character of the intruded with that of the contemporaneous masses in the same district, and, from the resemblance which may be traced between them, draw at the best but a doubtful inference as to their relative dates.

The contemporaneous traps always assume a bedded form, the intrusive occasionally do so; and the question naturally arises here, what are the tests whereby a bed of trap may be known to be contemporaneous and not intrusive? The answer is happily a simple one. An intrusive mass is found to alter to a greater or less extent the rocks in contact with it; if it occur as a dyke, then the beds on either side have been cut through and probably otherwise affected; if it take the form of a bed or sheet, the strata lying above and below it will be found to be both altered, showing evidently that a heated mass has been interposed between them, and consequently that the igneous rock is of later date than any of the strata among which it occurs. In the case of a contemporaneous melted trap, however, the appearances presented are different; it always takes the form of a flat bed corresponding to all the inclinations and curvatures of the sandstones, shales, limestones, or other strata among which it lies. If examined carefully, it may be found not unfrequently baking and contorting the bed that forms its pavement, but producing no change whatever on that which composes its roof. It may be capped and underlaid by layers of shale, and in such a case we might not improbably find the shale below it highly baked, so as to resemble a sort of rude pottery, while the shale above would present no sign of such metamorphism, but on the contrary might display its delicate plants or shells down to the very surface of the trap, and were the latter concealed from view we should never suspect, from the aspect of this shale, that any igneous rock existed in the neighbourhood. The inference to be drawn from such appearances seems very obvious. Had the upper shale been in

existence when the greenstone or basalt was erupted, it would have suffered an alteration similar to that produced on the shale below; and the fact, plain and palpable, that it has undergone no such change, shows pretty clearly that it was deposited at the bottom of the water after the trap had cooled and consolidated, and that consequently the trap must be intermediate in age between the beds on which it rests and those which lie above it; in other words, that it is a *contemporaneous* rock. Hence, if we know the exact geological position and age of the shales, we know also those of the associated trap, and can thus ascertain that at a certain definite period in the past history of our planet a particular district was the scene of volcanic action.

Examples of such contemporaneous traps abound among the carboniferous rocks of central Scotland, especially in Fife and the Lothians (Fig. 35). I may refer again to the vicinity of Edinburgh as affording some excellent illustrations. The eastern part of Arthur's Seat displays a series of basalts and greenstones which can be proved to have been thrown out during the times of the Lower Carboniferous rocks, at a period long anterior to that of the Burdiehouse limestone. The Pentland Hills exhibit on a much greater scale vast sheets of felspathic traps, such as felstones and tufas, traceable in some cases for six or seven miles, which were erupted at a still earlier period.[1] The trap pebbles in our boulder consisted of light yellow and pink felstone, and were derived, I make no doubt, from these Pentland Hill beds, when what forms now the cone of Carnethy, rising well-nigh 1900 feet above the sea, existed as one of a scattered archipelago of islets, or as a sunken rock battered by the waves that scattered its shingle along the floor of what may have been either a shallow sea or a shoaling estuary, where eventually the

[1] The geology of Arthur's Seat and Pentland Hills was admirably worked out more than quarter of a century ago by Mr. M'Laren. His work (already referred to) is unfortunately now out of print.

sand and pebbles hardened into that bed of coarse grey sandstone whence our boulder was derived.

The second class of contemporaneous trap-rocks are the tufas or volcanic ashes. They differ entirely in their aspect and origin from any of the rocks already described. Greenstones, basalts, felstones, and such like, were all melted rocks, thrust up from below as we see lava thrown out by a modern volcano, being styled contemporaneous when poured out along the sea-bottom or the land, and intrusive when they never reached the surface but cut through the strata below. The tufas, however, point to a totally different origin. They are of various shades of colour, according to their chemical composition. In East Lothian they assume a deep red hue; among the Pentland Hills they are often flesh-coloured, while in Linlithgowshire they range from a dull-brown to a pale leek-green, green being the prevailing tint. They always show a dull uncrystalline surface, irregularly roughened by included fragments of various rocks, such as trap, sandstone, shale, and many others. These fragments or *lapilli* vary in size from less than a pin-head up to large bombs of several hundredweight, and from being generally abundant give to the tufas one of their best-marked characteristics. The smaller pieces are usually more or less angular, and throughout the carboniferous series of Linlithgowshire consist chiefly of a pale felspathic matter, lighter in shade and commonly harder in texture than the matrix or paste in which they lie. In some localities, where the included pieces are larger, they have a rounded form, and often show a honeycombed vesicular surface, like balls of hardened slag. Fragments of sandstone have not unfrequently a semi-fused appearance, and plates of shale sometimes look like the broken debris from a tile-work, although in many instances these fragments may be found showing no trace whatever of alteration, being undistinguishable from the neighbouring sandstones and shales from which they probably came. I have seen in some of the coarser

tufas, or rather volcanic conglomerates, enormous masses of basalt and greenstone buried deep in the surrounding green or red felspathic paste, and showing on their more prominent edges the usual vesicular cavities. In such conglomerates there is usually no division into beds; the whole mass, indeed, forms a bed between lower and higher strata, but internally it shows for the most part no trace of stratification. In these confused assemblages one may occasionally light upon detached crystals of augite or other mineral scattered irregularly through the tufa. Their angles will be found often blunted, and the crystals themselves broken, appearances which have likewise been noticed among the ash of modern volcanoes. When the tufas are finer grained they usually exhibit a well-marked stratification, and can often be split up into laminæ like an ordinary fissile sandstone. Organic remains not unfrequently abound in such laminated beds, and vary in their character as widely as in any other stratified rock, being sometimes land-plants, sometimes sea-shells.

Such are some of the more obvious characters of the volcanic ashes or tufas, as developed among the carboniferous rocks of central Scotland. Their great varieties of composition and general aspect render them a somewhat difficult set of rocks to master, but when fairly and fully understood they soon prove themselves to be by far the most interesting section of the traps, for one needs seldom to hesitate a moment as to their origin or date, while their fossil contents impart to them an interest all their own. By comparing such rocks with the consolidated ash or fine dust and *lapilli* of a modern volcano, a remarkable resemblance of external characters is found to subsist; and this likeness holds sufficiently close, when pursued into details, to show that the ancient and the modern rocks have resulted from the same source, that, namely, of volcanic eruption. The ash of active burning mountains falls down their sides loosely and incoherently, every successive shower of

dust or scoriæ settling without much regularity on those that have gone before. The ash of the old carboniferous eruptions, however, was showered for the most part over the sea or across wide shoaling estuaries, at least it is only such portions of it as fell there that have come down to our day. Settling down among the mud and sand at the bottom, the volcanic matter accumulated in wide horizontal beds, every marked inequality being smoothed down by the currents until a series of regularly stratified layers came to be formed, entombing any organisms that might find their way to the bottom or be lying there at the time. The ash of terrestrial volcanoes has no marked stratification because thrown out in open air, while that of the carboniferous rocks of central Scotland is distinctly bedded from having been deposited under water.

Tufas and contemporaneous melted traps are very generally found together interstratified regularly with each other, and the inference to be drawn from their juxtaposition is of course simply this, that at one time liquid lava rolled along the bottom of the water, while at another showers of volcanic dust and cinders settled down in successive beds. This active play of the igneous forces took place at the mouths of estuaries or farther to sea; and it is accordingly sometimes not a little interesting to trace, amid the sediment that accumulated below the water during the pauses between the eruptions, well-preserved remains now of plants that had come drifting from the land, anon of slim spirifers, and producti that swarmed upon the hardened lava-streams, and amid the thickening volcanic mud that slowly sank to the sea-bottom. Such a sequence of events will be made plain from the following section, the materials of which are derived from different parts of the trappean region of Linlithgowshire. The undermost bed here shown (1) is one of marine limestone, abounding with encrinal joints, corals, spirifers, and other undoubtedly marine organisms. Above it comes a layer of tufa or volcanic ash (2) of a dull green aspect, the boundary

line between the two rocks lying as clear as if the quarryman had marked it off with his foot-rule. The upper part of the ash, however, does not show an equally clear line of demarcation with the stratum above. On the contrary, it gradually changes its character, becomes more calcareous as it goes up, with here and there a stone-lily joint or a stray productus, until these organisms increase so much in number that the rock insensibly passes into an ordinary limestone (3) like that below. Next succeeds a thin seam of ash (4) resting sharply on the limestone and overlaid by a bed of shale (5) containing the same marine organisms. Another stratum of ash (6) resembling those below follows the shale, and is surmounted by a close compact greenstone (7) that hardens the ash on which it rests, but produces no apparent alteration on the soft fissile shale (8) above it. Next is a fourth seam of volcanic ash (9) resembling those below it, but without any shells or crinoidal joints, the only fossils observable being a few carbonized stems apparently of calamites and lepidodendra. Above it comes a bed of white quartzy sandstone (10) with similar vegetable remains, and then a layer of white stiff fire-clay (11) with rootlets of stigmaria, above which lies a seam of coal (12). A thin layer of soft blue shale (13) here intervenes, somewhat baked along its upper portions by another bed of compact vesicular greenstone (14), which displays in places a well-marked columnar structure. It is

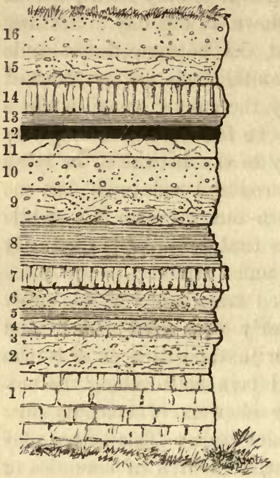


Fig. 35 —Contemporaneous Trap.

surmounted by a highly characteristic ash ([15]), in which there occur numerous large bombs chiefly of trap of different kinds, some of them highly vesicular. Fragments of shale also occur, mingled here and there with black carbonized fragments of coal-measure plants, but without any of the shells and other marine organisms so abundant below. The topmost bed is a grey carbonaceous sandstone ([16]), underlying a thin covering of vegetable mould.

Such is the skeleton, as it were, of the section ; the mere dry bones which remain to the geologist, and which he must study closely to be able to give them life again. The lowest bed visible, with its stone-lilies and molluscs, we readily recognise as marking an old ocean-bed, so that the little episode in the primeval records of our planet here presented to us opens, like the two great epics of antiquity, within sound of the wide-roaring sea. The seam of ash which follows shows, from the sharpness of its line of demarcation with the limestone, how the denizens of the sea-bottom were suddenly destroyed by a thick shower of volcanic dust that settled down over their remains. The waters, however, soon cleared, and ere long stone-lilies and producti were plentiful as ever, mingling their remains among the upper layers of the soft muddy ash, and giving rise therefrom to a sort of calcareous ash or ashy limestone, until in the course of time the volcanic matter became wholly covered over by a seam of ordinary limestone. The corals and stone-lilies were, however, anew destroyed by the deposition of volcanic dust that settled over them as a seam of ash, after which the water was again rendered turbid and muddy by the inroad of foreign matter, which, brought down by rivers or by the changing currents of the ocean, sank to the bottom and eventually consolidated into a seam of shale. Thereafter the volcanic forces began once more to eject a quantity of dust and scoriæ that fell into the water and spread along the bottom as a stratum of ash, and to pour out a current of lava which hardened into a great sheet visible now as the undermost greenstone of the section.

The emission of the lava seems to have terminated the eruption, for the next stratum is one of shale like that below the ash, so that the muddy sediment, the deposition of which was interrupted for a while by the volcanic products, began afresh to settle down along the sea-bottom. This last condition of things seems to have continued for a considerable period, seeing that the shale bed is relatively thick, and from its fissile laminated structure indicates a slow and tranquil deposition. Another eruption of volcanic dust and ashes again interrupted the detrital deposits, and gave rise to another seam of tufa. This last subterranean movement seems to have considerably altered the general contour of the sea-bottom, and so elevated it, at least at one part, that a thick accumulation of sand, and subsequently of clay, filled it up to the level of the water or nearly so, giving rise to a dense growth of the stigmaria and other coal-measure plants whose roots are still seen imbedded in the fire-clay on which, as a soft muddy soil, they originally grew. It is probable, however, that, notwithstanding such elevations of the sea-bed, there was a general subsidence of the ground during the accumulation of these strata, for we see that the peaty morass, represented now by the coal-seam, ere long sank beneath the waters, with the inroads of which it was unable to keep pace, while there slowly silted over it a muddy sediment that hardened at length into what is now a seam of shale. But this order of things had been in existence for but a comparatively short period when the igneous forces broke out again, ejecting a stream of molten lava that spread along the bottom of the shallow waters and hardened as before into a sheet of greenstone. This was followed by an abundant shower of dust and lapilli, along with numerous large masses of greenstone and basalt. These falling into the water accumulated on the upper surface of the lava-stream, then somewhat cooled, and formed in the end a stratum of ash of a rubbly conglomeritic aspect. That the sheet of greenstone really spread out along the sea-bottom before the

ejection of the ash, and was not intruded among the beds at a later period,—that, in short, it must be regarded as a contemporaneous and not as an intrusive rock, seems sufficiently shown by its great regularity and evenness, and by the unaltered condition of the fine soft felspathic matter which covers its upper surface. It was assuredly in a highly-heated condition when poured out, as may be gathered from the baked aspect of the mud over which it rolled; but it had cooled and solidified, at least along its upper surface, ere buried beneath the shower of ashes. The last bed exhibited in the section is a grey sandstone, with many carbonaceous streaks and traces of land-plants, showing a pause in the volcanic activity of the district, during which the streams from the land brought down sandy sediment, with an abundant admixture of macerated leaves, branches, and other drift-wood.

It thus appears that not only were the plains and hills of the Carboniferous era richly clothed with vegetation, and its waters crowded with animals, but that then, as now, subterranean forces were at work, sometimes elevating, sometimes depressing the area alike of the land and of the sea; while, not unfrequently, melted lava rose from below, rolling along the bottom of the waters, and showers of ashes were flung far and wide through the air, settling at last as a thickening sediment along the floor of the sea, or athwart the marshy swamps of the delta. Whether the interior of the land had burning cones among its pine-covered hills we know not yet. Such, however, probably existed; nay, there may have been among the higher peaks some "snowy pillar of heaven," like the Ætna of Pindar, raising its smoking summit among everlasting crags of ice in solitudes lifeless and bare.[1]

[1] The highest points of New Zealand, nearly 10,000 feet above the sea, are said to be clothed for two-thirds of their height with ice and snow. If, therefore, during Carboniferous times, there existed somewhere to the west of what is now central Scotland, a chain of hills 5000 or 6000 feet high, their summits might perhaps have been as wintry as that of Mont Blanc.

Our boulder has served us like the minstrels in modern Gothic poetry, who appear between the cantos, and give an air of unity and completeness to what would otherwise be often rambling and unconnected. And now, at the close, it comes again before us, lying in its bed of clay, clustered with mosses of brightest green, and overshadowed by its flickering canopy of beechen leaves. Silent and senseless, the emblem, seemingly, of calm repose and unchanging durability, what could we have conceived it should have to chronicle, save the passing, perchance, of many a wintry December and many a sultry June. Such, indeed, would be the character of its records of the centuries that have passed away since the birth of man, did any such record survive in its keeping. But it rests there as the memorial of far earlier centuries, and of an older creation; and though now surrounded with all that is lovely or picturesque—the twinkling flowers on every side, the wide arch of boughs overhead, and the murmuring streamlet in the dell below—and though forming itself no unimpressive object in the scene, the boulder looks out upon us unconnected with anything around. Like a sculptured obelisk transported from the plains of Assyria to the streets of London, it offers no link of association with the order of things around it; its inscriptions are written in hieroglyphics long since extinct, but of which the key yet remains to show us that the rocks of our planet are not masses of dead, shapeless matter, but chronicles of the past; and that all the varied beauty of green field and waving wood is but a thin veil of gossamer spread out over the countless monuments of the dead. We have raised one little corner of this gauze-like covering, and tried to decipher the memorials of bygone creations, traced in clear and legible characters on the boulder. First, there lies spread out before us a wide arctic sea, studded with icebergs that come drifting from the north. Here and there a bare barren islet rises above the waste of waters, and the packed ice-floes often strand along its shores, while at other parts great towering bergs, aground in mid-ocean, keep rising and falling

with the heavings of the surge, and seem ever on the verge of toppling into the deep. But this scene, so bleak and lifeless, erelong fades away, and we can descry a wide archipelago of islands, green well-nigh to the water's edge, and looking like the higher hill-tops of some foundered continent. The waves are actively at work wearing down the shores, which present for the most part an abrupt cliff-line to the west. This picture, too, gets gradually dim, and when the darkness and haze have cleared away, the scene is wholly new. For miles around there spreads out an expanse of water, like a wide lake, thickly dotted with islets of every form and size, clothed with a rich vegetation. Here a jungle of tall reeds shoots out of the water, clustering with star-like leaves; there a group of graceful trees, fluted like the columns of an ancient temple, and crowned by a coronal of sweeping fronds, spread out their roots amid the soft mud. Yonder lies a drier islet, rolling with ferns of every shape and size, with here and there a lofty tree-fern, waving its massive boughs high overhead. The vegetation, rank and luxuriant in the extreme, strikes us as different from anything visible at the present day, though, as our eyes rest on the muddy discoloured current, we can mark, now and then, huge trunks, branchless and bare, that recall some of the living pine-trees. The denizens of the water seem to be equally strange. Occasionally a massive head, with sharp formidable tusks, peers above the surface, and then the gleam of fins and scales reveals a creature some twenty or thirty feet long. Glancing down into the clearer spots, we can detect many other forms of the finny tribes, all cased in a strong glistening armature of scales, and darting about with ceaseless activity. Beyond this scene of almost tropical luxuriance, on the one side, lies the blue ocean, with its countless shells and corals, its stone-lilies and sea-urchins, and its large predaceous fish; on the other side stretches a far-off chain of hills, whose nether slopes, dark with pine-woods, sweep down into the rich alluvial plains. And then this landscape, too, fades slowly away, and thick darkness descends

upon us. Yet through the gloom we feel ever and anon the rumbling earthquake, and see in the distance the glare of some active volcano that throws a ruddy gleam amid the pumice and ashes, ever dancing along the surface of the sea. And now this last scene melts away like the rest, and dark night comes down in which we can detect no ray of light, and beyond which we cannot go. The record of the boulder can conduct us no further into the history of the past.

The same principles which have been pursued in the previous pages in elucidating the history of the Carboniferous system, will conduct the reader to the true origin and age of any group of rocks he may encounter, whatever its nature, and wheresoever its locality. Let him, therefore, in his country rambles, seek to verify them in valley and hillside, by lake and cataract, and along river-course and sea-shore. Let him not be content with simply admiring the picturesque grouping of rock-masses, but rather seek to interpret their origin and history, tracing them step by step into the past, amid ages long prior to man. Such a process will give him a yet keener relish for the beauties of their scenery, by ever calling up to his mind some of those striking contrasts with which geology abounds. In the stillness of the mountain-glen, he will see on every side traces of the waves of ocean, and when dipping his oars into the unruffled sea among groups of wasted rocks, miles from shore, he will bethink him, perchance, of some old forest-covered land, of which these battered islets are the sole memorials. His enjoyment of the scenery of nature is thus increased manifold, and he carries about with him a power of making even the tamest landscape interesting. Cowper, in one of his exquisite letters, remarks,—"Everything I see in the fields, is to me an object; and I can look at the same rivulet or at a handsome tree, every day of my life, with new pleasure." Had the sweet singer of Olney lived to witness the results obtained by the geologists whom he satirized, he would perhaps have sauntered along the Ouse with a new pleasure, and have felt a yet more intense delight in

casting his eyes athwart the breadth of landscape that spreads out around the " Peasant's nest."

Such, however, are after all only secondary incentives to the study of the rocks. As a mental exercise, geology certainly yields to none of the other sciences, for it addresses itself at once to the reasoning powers and to the imagination, and may thus be made a source both of intellectual training and of delightful recreation. Of none of the sciences is it so easy to get a general smatter, yet none is so difficult thoroughly to master, for geology embraces all the sciences. In so wide a field, the student will therefore find ample room to expatiate. In beginning the study, he may perhaps think it, as Milton pictured the other paths of learning, " laborious, indeed, at the first ascent; but else so smooth, so green, so full of goodly prospects and melodious sounds on every side, that the harp of Orpheus was not more charming." If time and taste disincline him to travel over the whole of the broad field, there are delightful nooks to which he may betake himself, replete with objects of beauty and interest, where he may spend his leisure, and by so doing not merely delight himself, but enlarge the bounds of human knowledge. No part of the domain can be too obscure or remote to reward his attention; no object too trifling or insignificant: for the march of science, though a stately one, proceeds not by strides, but by steps often toilsome and slow; and she stands mainly indebted for her progress not to the genius of a few gigantic intellects, but to the united efforts of many hundred labourers, each working quietly in his own limited sphere.

But the highest inducement to this study must ever be that so quaintly put by old Sir Thomas Browne: "The world was made to be inhabited by beasts, but studied and contemplated by man: 'tis the debt of our reason we owe unto God, and the homage we pay for not being beasts; without this the world is still as though it had not been, or as it was before the sixth day, when as yet there was not a creature that could conceive

or say there was a world." Geology lifts off for us the veil that shrouds the past, and lays bare the monuments of successive creations that had come and gone long ere the human race began. She traces out the plan of the Divine working during a vast cycle of ages, and points out how the past dovetails with the present, and how the existing condition of things comes in as but the last and archetypal economy in a long progressive series. By thus revealing what has gone before, she enables us more fully to understand what we see around us now. Much that is incomplete she restores; much that is enigmatical she explains. She teaches us more fully man's true position in the created universe, by showing that in him all the geologic ages meet—that he is the point towards which creation has ever been tending. How far the facts brought to light by geology may bear upon the future, will not, perhaps, be solved until that future shall have come. There is, nevertheless, in the meanwhile, material enough for solemn and earnest reflection, and as years go by the amount will probably be always increasing. For we must ever be only learners here, and when all earthly titles and distinctions have passed away, and we enter amid the realities of another world, we shall carry with us this one common name alone. It will, perhaps, be then as now, that only

> "In contemplation of created things
> By steps we may ascend to God."

And it can surely be no unmeet preparation for such a scene, in humble faith to read the records of His doings which the Almighty has graven on the rocks around us. Many problems meet us on every hand—problems which it seems impossible for us now to solve—and as the circle of science ever widens, its enveloping circumference of difficulty and darkness widens in proportion. It is, doubtless, well that it should be so; for we are thus taught to regard our present state as imperfect and incomplete, and to long for that higher and happier one promised by the Redeemer to those that love Him, when "we shall know thoroughly even as we are thoroughly known."

TABLE OF FOSSILIFEROUS ROCKS.

LYELL'S *Elements*, p. 109.

1. RECENT. 2. POST-PLIOCENE.	POST-TERTIARY.	
3. NEWER PLIOCENE. 4. OLDER PLIOCENE.	PLIOCENE.	TERTIARY or CAINOZOIC.
5. UPPER MIOCENE. 6. LOWER MIOCENE.	MIOCENE.	
7. *a* UPPER EOCENE. 7. *b* MIDDLE EOCENE. 8. LOWER EOCENE.	EOCENE.	
9. MAESTRICHT BEDS. 10. UPPER WHITE CHALK. 11. LOWER WHITE CHALK. 12. UPPER GREENSAND. 13. GAULT. 14. LOWER GREENSAND. 15. WEALDEN.	CRETACEOUS.	SECONDARY or MESOZOIC.
16. PURBECK BEDS. 17. PORTLAND STONE. 18. KIMMERIDGE CLAY. 19. CORAL RAG. 20. OXFORD CLAY. 21. GREAT or BATH OOLITE. 22. INFERIOR OOLITE. 23. LIAS.	JURASSIC.	
24. UPPER TRIAS. 25. MIDDLE TRIAS, or MUSCHELKALK. 26. LOWER TRIAS.	TRIASSIC.	
27. PERMIAN, or MAGNESIAN LIMESTONE.	PERMIAN.	PRIMARY or PALÆOZOIC.
28. COAL-MEASURES. 29. CARBONIFEROUS LIMESTONE.	CARBONIFEROUS.	
30. UPPER DEVONIAN. 31. LOWER "	DEVONIAN, or OLD RED SANDSTONE.	
32. UPPER SILURIAN. 33. LOWER "	SILURIAN.	
34. UPPER CAMBRIAN. 35. LOWER "	CAMBRIAN.	

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